

# **A STUDY ON DEVELOPMENT IN ENGINEERING PROPERTIES OF DENSE GRADE BITUMINOUS MIXES WITH COAL ASH BY USING NATURAL FIBER**

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# **A STUDY ON DEVELOPMENT IN ENGINEERING PROPERTIES OF DENSE GRADE BITUMINOUS MIXES WITH COAL ASH BY USING NATURAL FIBER**

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## Certificate

This is to declare that the work in the thesis entitled “**A STUDY ON DEVELOPMENT IN ENGINEERING PROPERTIES OF DENSE GRADE BITUMINOUS MIXES WITH COAL ASH BY USING NATURAL FIBER**” by **Saswat Biswapriya Dash** is a record of an unique work carried out by him under my supervision and regulation in partial fulfillment of the requirement for the award of the degree of **Master of Technology** in **Department of Civil Engineering** with specialization of **Transportation Engineering**. Neither this report nor any part of it has been submitted for any degree or academic award elsewhere.

Prof. Mahabir Panda

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Date:

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## Abstract

Coal-based thermal power plants have been a key source of power generation in India. The prime waste product of a coal thermal power plant are fly ash and bottom ash. Heavy dumping of these waste products causes fatal environment pollution to air, water, and land, besides impairing human health. This research work is done to deliver the optimum use of ash, namely bottom ash as fine aggregate and fly ash as mineral filler with natural fiber (such as sisal fiber) used to improvise the engineering properties of bituminous paving mixes. For national interest these waste products, which are available easily and abundantly can be used economically for bituminous paving purpose, which ultimately helps in saving the natural aggregate resources of the nation.

In the present study, dense graded bituminous mix specimens are prepared using natural aggregate as coarse aggregates, bottom ash as fine aggregates, fly ash as filler and sisal fiber as additive. Proportion of aggregate for dense graded bituminous macadam (DBM) grading has been considered as per MORTH (2013) having nominal maximum aggregate size (NMAS) 26.5 mm. To strengthen the mix, slow setting emulsion (SS1) coated sisal fiber is added in varying percentage of 0, 0.25%, 0.5%, 0.75%, and 1% by weight of the mix, with different length variations such as 5mm, 10 mm, 15 mm and 20 mm. At the initial stage of the research, specimens were prepared with two types of paving bitumen i.e. VG30 and VG10, out of which the initial trials resulted better Marshall characteristics with VG30 bitumen and hence was considered for subsequent study. Detailed study with Marshall test results were used to determine the Marshall characteristics, optimum binder content and also optimum fiber content including the optimum length of fiber. Marshall stability as high as 15kN was obtained with optimum bitumen content of 5.57%, with optimum fiber content of 0.5% with optimum fiber length of 10 mm. Further, for delivering the performances of the pavement, various performance tests were also conducted such as moisture susceptibility test, indirect tensile strength (ITS), creep test and tensile strength ratio of bitumen mixes. It is finally observed that not only satisfactory, but also much improved engineering properties result with coal ash as fine aggregate and filler, stabilized with natural sisal fiber duly coated with SS-1 emulsion in advance.

Utilization of non-conventional aggregate like coal ash and natural fiber together thus may help to find a new way of bituminous pavement construction. The coal ash dumping which is a serious concern to everyone in respect of its disposal and environmental pollution, can find one way for its reuse in an economical way by substituting natural resources of sand and stone dust.

**Key word:** *Bottom ash, Fly ash, Sisal fiber, Emulsion, Indirect tensile strength, Static creep test, Tensile strength ratio.*

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## **LIST OF ABBREVIATIONS**

HMA	:	Hot mix asphalt
DBM	:	Dense bound macadam
MORTH	:	Ministry of Road Transport & Highways
OBC	:	Optimum Binder Content
ITS	:	Indirect tensile strength test
TSR	:	Tensile strength ratio
VA	:	Air void
VMA	:	Void in mineral aggregates
VFB	:	Void filled with bitumen

## LIST OF SYMBOLS

$G_{mb}$	:	Bulk specific gravity of aggregate
$G_{se}$	:	Effective specific gravity of aggregate
$M_b$	:	Mass of bitumen used in mix
$G_b$	:	Specific gravity of bitumen
$G_a$	:	Apparent specific gravity
$G_{mm}$	:	Theoretical maximum specific gravity of mix
$G_{mb}$	:	Bulk specific gravity of mix
$P_s$	:	Percentage of aggregate present by total mass of mix
$S_t$	:	Indirect Tensile Strength
$S_2$	:	Soaked stability
$S_1$	:	Standard stability



## Structure of thesis

The thesis structure is arranged as follows:

**Chapter 1-** gives a brief description about the background of the research and bituminous mix design. The problem statement and objectives of the research are also summarized.

**Chapter 2-** deals with the literature review of bottom ash fly ash and different fibers. It also summarize the literature study based on the properties of various bituminous mix using coal ash and fiber.

**Chapter 3-** deals with description of raw materials used for this research work.it also give the physical and chemical properties of the materials.

**Chapter 4-** describes the experimental work done to ensure the performance characteristics of the DBM mixture made from coal ash and sisal fiber. The experimental work includes Marshall propeties analysis, Indirect Tensile Strength test (ITS), Tensile strength ratio, Retained stability test and Static creep test.

**Chapter 5-** deals with the result analysis of several test results for modified and unmodified DBM mixes.

**Chapter 6-** summarizes the research work done so far and recommend future work plan.

# CHAPTER 1

## INTRODUCTION

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### 1.1. Background of the study

Pavements or highways or roads are regarded as country's backbone, upon which its upswing and progress depend on. All countries normally have a series of programs for building a new road infrastructures or emerging the existing one. Construction of both flexible and rigid pavement include a gross amount of investment to reach better performance oriented and smooth quality of pavement that will endure for long time. In India, where highways are considered as the primary function of transportation, Government of India have been investing a huge amount of money for developing the pavement construction and maintenance. A detailed engineering study may retain significant amount of investment and pavement materials, which in turn achieve a reliable performance of the in-service highway. Regarding flexible pavement, two major facts are taken into considerations i.e. pavement design and mix design. The present research study is focused on engineering property of bituminous mixes prepared from alternate or nonconventional materials.

### 1.2. Bituminous mix design

#### 1.2.1. Overview on bituminous mix design

From the review of Das et al. (2004); it is known that the bituminous paving technique was first introduced on rural roads during 1900's. The formal mix design method was first made possible by Hubbard field method, which was originally developed for the sand-bituminous mixture. But one of the focal limitation of this technique was its incompatible of handling large aggregates. Later on, a project engineer Francis Hveem of California Department of Highways, developed an instrument called Hveem stabilometer to calculate the possible stability of the mixture. At the early stage, Hveem did not have any experience to estimate the amount of optimum bitumen that will just be right for mix design. He adopted the surface area calculation concept used for cement concrete mix design, to assess the quantity of bitumen vital for the mixture. On the other hand,

Bruce Marshall developed equipment to test stability as well as deflection of the bituminous mixture. It was adopted by the US Army Corpse of Engineers in 1930's and successively adapted in 1940's and 50's.

### **1.2.2. Bituminous mix design**

Bituminous pavement comprises of a mixture of stone chips, graded from nominal maximum aggregates size (NMAS), through the fine fraction smaller than 0.075 mm mixed with appropriate amount of bitumen that can be compacted adequately with smaller air voids and will have adequate dissipative and elastic properties. The aim of bituminous mix design is to determine the fair proportion of bitumen and aggregates fraction to yield a mixture that is effective, durable, reliable and economical.

### **1.2.3. Types of bituminous mixes**

Bituminous mixes are combination of mineral aggregate and binder that are mixed with their optimum value to lay down and compacted in layers for building smooth road. Mixing of bitumen and mineral aggregates are done in several ways, which are listed below.

#### **(a) Hot mix asphalt**

Commonly known as HMA, is prepared by heating bitumen binder and moisture dry aggregate to a mixing temperature of 150 °C to 160 °C (300 °F to 330 °F) which will provide a consistent mixture to work with. Due to high temperature of the mixture it is possible to compact the mixture to its optimum air content to give better stability than others. There as on being which HMA is widely used on highly trafficked roadways such as highways, airfields, and racetracks.

#### **(b) Warm mix asphalt**

Frequently known as WMA, is prepared by mixing aggregate and binder at a moderate temperature of 100 °C to 135 °C. The virgin binder is modified with foreign additives prior to mix, which will help bitumen binder to mix properly with mineral aggregate. Due to low temperature of mixing, consumption of fuel and emission of harm gasses are comparatively lower than hot mix. Not only

had it improved workability, but also the low-temperature laying helps in accessing road surface much quickly.

### **(c) Cold mix asphalt**

This technique is practiced where high mixing temperature is a problem. The aggregate is blended with an emulsified bitumen (a combination of water and bitumen in a proper ratio) to a mixture that is easy to work and compact. When water evaporates from emulsion leaving back bitumen, the cold mix will, ideally, take on the properties of cold HMA. Cold mix is frequently used as a patch material on a lesser trafficked roads.

### **(d) Cut-back asphalt**

A lighter fraction of petroleum is dissolved with bitumen binder to produce a less viscous liquid that will dissolve with the aggregate and evaporate after compaction is done. Cutback bitumen has been widely used in contradiction due to its nonpolluting characteristic and easy to work with.

### **(e) Mastic asphalt or sheet asphalt**

Mastic asphalt is made by heating hard grade blown bitumen (oxidation) in a green cooker (mixer) until it has turns to a viscous liquid before it is added to aggregates. The mixture is cooked for 6-8 hours to mature and once the mixer is ready, it is transported to the site where it generally laid in different thickness for footpath, road and for flooring or roof applications.

## **1.2.4. HOT MIX ASPHALT**

Hot Mix Asphalt (HMA) is mixture of aggregate and bitumen that are mixed, placed and compacted at higher temperature. The three types of HMA are Dense Graded Bituminous Macadam (DBM), Stone Matrix Asphalt (SMA) and Open graded mix.

### **(a) Dense Graded Bituminous Macadam (DBM)**

This type of bituminous mix is a well-graded HMA with proper proportion of all aggregate fraction. It is hard and relatively impermeable. Dense-graded mixes are classified as fine-graded and coarse graded.

### **(b) Stone Matrix Asphalt (SMA)**

Stone matrix asphalt (SMA), which is occasionally called as Stone Mastic Asphalt, is a gap-graded mix, eventually developed to maximize the rutting resistance caused by heavy traffic. SMA has a high coarse aggregate fractions that interlocks to each other, to form a stone skeleton that resists permanent deformation. SMA is preferably used for surface courses on high volume roads. Mineral filler sand additives are used to check the drain-down of bitumen binder during construction.

### **(c) Open-Graded Mixes**

Unlike DBM and SMA, an open-graded mix is made-up of only stone chip sand bituminous binder. Due to absence of Fine aggregate and filler it became porous and offers surface water to drain down quickly. It is used as a drainage layer under dense-graded HMA, SMA or PCC. It has enough friction with relatively little strength than other. It is purposefully constructed with high air void that reduce road tire noise by up to 50%.

## **1.3 Problem Statement**

For preparation of bituminous mixes, commonly aggregates, inform of coarse, fine and filler fractions are used. In many locations, the aggregates in different size fractions are not easily available, use of which needs procurement from long distances and hence increases the cost exorbitantly. On the other hand, a number of coal-based thermal power plants have been set up to somewhat cater to the power supply requirement. It is reported that around 120 Million Tons of ashes are producing from forty major thermal power plants per year in India. Most of the coal ash has likely to dispose of either dry or wet to an open areas, which are available near the factory or by grounding into artificial lagoon or dumping yards. Such a vast quantity of these type of waste material does pose challenging problems, in the form of land usage, health hazards, and environmental dangers. Both in disposal as well as in utilization, utmost care has to be taken to safeguard the interest of human life, wildlife and environment. Hence to suppress the wretched effect of these materials, a detailed study is necessary to utilize them in a productive way that will satisfy the society need.

## **1.4. Objectives of research**

This experimental study has done to enable the most appropriate use of coal ash as nonconventional aggregate along with natural fiber (Sisal fiber) as an additive by ensuring the adequate performance result in the field of fatigue, moisture susceptibility, and creep value. Again the possible effects of fiber on bitumen mixes are also taken into consideration, and comprehensive study was done to find the optimum fiber content and fiber length that will increase the engineering property of bituminous mix.

## **1.5. Scope of the study**

- The significant scope of this study is to use coal ash as a fine material in HMA mix design and thus producing a good quality and smooth surface road which may be commercially acclaimed and can with stand in any possible environment condition.
- Again Utilization of non-conventional materials like coal ash and natural fibers together thus may help to find a new way of bituminous pavement construction. The coal ash dumping which is a serious concern to everyone in respect of its disposal and environmental pollution, can find one way for its reuse in an economical way by substituting natural resources of sand and stone dust.

In this research work a comparative study has been done on Dense graded bituminous macadam (DBM) by focusing on the following highlight

1. Marshall properties study of mixes on DBM using,
  - a) With fiber and coal ash
  - b) With fiber and without coal ash
  - c) Without coal ash and with fiber
  - d) Without fiber and coal ash
2. The performance characteristics of bituminous mix
  - (a) Under moisture condition with and without fiber and coal ash ·

- Tensile strength ratio test
  - Retained stability test
- (b) Under thermal cracking (Tensile strength test) of DBM mix with and without fiber and coal ash
- (c) Under permanent deformation (Static creep test) of mixes with and without fiber and coal ash

## CHAPTER 2

# REVIEW OF LITERATURES

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### 2.1 General reviews about bottom ash, fly ash and sisal fiber in different bituminous mixes

**Shuler, T. S. (1976)** performed a laboratory study on six bottom ash obtained throughout the state of Indiana and tried to physically characterize the materials. Tests included Unit weight, Florida Bearing Test, Hveem Centrifuge Kerosene Equivalent and Oil Ratio Specific Gravity, Dry Sieve Analysis, and a degradation analysis. Performance tests are also done by Florida Bearing Test on fine aggregate-ash mixtures prior to mix with bitumen; Marshall Stability on specimens in the dry as well as the soaked condition, Hveem Stability and Cohesion and Skid Resistance.

Bituminous mixtures with ash demonstrated higher values for retained stability in the Water Sensitivity Test than mixtures without ash, Skid resistance of the mixtures was enhanced with the addition of ash

**R. E. Long and R.W. Floyd (1982)** studied that aggregate shortages and increased transportation costs have greatly increased prices of related construction items in areas of Texas which is not blessed with natural aggregates. Some natural aggregates are not performing up to expectations as documented by stripping, rutting and other visual signs of pavement distress noted throughout the Department. Because of these spiralling construction costs and need to field evaluate bottom ash, District 1, supported by the Materials and Tests Division, decided to construct three field test pavements substituting bottom ash for part of the natural aggregates in hot mix asphaltic concrete (HMAC).

They conclude that that bottom ash blend mixes require more asphalt than natural aggregates, mixes produce lower compacted density, mixes cool fast, requiring adequate rollers working



closely behind the laying operation, mixes exhibit high internal friction with no lateral displacement during compaction, this mix has maintained acceptable skid values after 14 months of interstate traffic, the cost of bottom ash blend mixes is somewhat higher based on additional asphalt used and aggregate transportation costs.

**David Q. Hunsucker (1992)** conducted an experimental bituminous surface overlay, which was placed in October 1987 on State Route 3 in Lawrence County, Kentucky. The experimental section utilized bottom ash aggregate, limestone and natural sand aggregate.

He conclude that because of the absorptive characteristics of bottom ash aggregate, nearly fifty percent more bitumen is required in the mixture. The increased asphalt content results in a higher unit bid price for the bituminous concrete material. The combination of bottom ash aggregates with limestone and natural sand aggregate appears to improve the overall performance of a bituminous surface mixture, especially with respect to its skid resistant properties.

**Musselman et al. (1994)** performed a two year demonstration project has been initiated where bottom ash was used as a 50% substitute aggregate in a asphalt pavement. The demonstration project includes noteworthy testing of possible environmental influences and pavement performance both in the laboratory and at the demonstration roadway. Data was gathered which include analytical data on groundwater and surface water quality impacts, surface run-off and suction lysimeter samples. Physical roadway performance was monitored through remote sensing using strain resistance and temperature probes as well as in situ and destructive pavement analysis.

They conclude that the use of bottom ash as a fractional substitute for conventional aggregate in pavement seems to be a feasible ash utilization skill. Bottom ash fraction of somewhat less than 50% is suggested for future testing. Gyratory test methods were done which was successful in predicting better pavement performance at a lower asphalt content in comparison with the Marshall test methods. Public acceptance of the concept of ash utilization in this fashion was obtainable for this demonstration project.

**Khaled Ksaibati and Jason Stephen (1999)** studied the possible utilization of incorporating bottom ash in bitumen mixes. For the field evaluation in this research project, a test pavement section was constructed with control bottom ash and bitumen mixes. Laboratory testing was done by using the Georgia Loaded Wheel Tester (GLWT) and Thermal Stress Restrained Specimen Tester (TSRST).

Laboratory evaluations shown that, with the various percentage of bottom ash in bitumen mixes possess significantly difference in high-temperature rutting and low-temperature cracking. The statistical analysis from GLWT test specify that the laboratory asphalt mixes possessed notable difference in high-temperature rutting characteristics while the analysis from TSRST results indicate that the laboratory mixes possessed outstanding result in low-temperature cracking characteristics when compared to each other.

**Menglan Zeng and Khaled Ksaibati (2003)** examined the moisture induced damage of bitumen mixtures comprising bottom ash. Eight bitumen mixtures made with one type of bitumen cement, two kinds of aggregate, three sources of bottom ash, and lime additive were estimated by using the principles written in AASHTO T283.

The addition of lime considerably upgrade the moisture induced damage of the asphalt mixtures as measured by TSR (recommended TSR value should be greater than 80%). Asphalt mixtures with the stone chips had higher indirect tensile strength (ITS) values as compared to the limestone aggregate in dry condition. The addition of lime or bottom ash did not significantly change ITS values.

**Khaled Ksaibati and Shiva Rama Krishna Sayiri (2006)** evaluated the performance of bitumen mix using bottom ash from three power plants in Wyoming. A laboratory evaluation and field evaluation was dono to study the possible effect of bottom ash in pavement. The laboratory experiment was done by testing the sample for rutting, stripping, and low temperature cracking. The field study was carried out with the Falling Weight Deflectometer (FWD). In addition to the laboratory and field evaluation the Pavement Condition Index (PCI) values was also evaluated.

The field and laboratory evaluations shows that 15% substitution of of bottom ash will not cut down the performance of bituminous pavement. The GLWT results show that limestone mixes with or without bottom ash have analogous rut depth resistance. Nitrogen analysis results indicate that bottom ash mixes may be more resistant to moisture induced damage.

**Shuler, T. S., et al. (2012)** studied the feasibility of bottom ash for HMA, that is to be used in the intermediate courses of the flexible pavements particular in binder course. The results obtained from the study explain that the mixture performed better when 15% of bottom ash was added to the mixture in replacement of correspond amount of sand. It is also observer that with increase in asphalt content, wearing resistance of the mixes increases accordingly.

The test results indicate that there is no deteriorating in mechanical properties of the bituminous mix in contrast to the conventional mix. However the mechanical and chemical characteristic of the tested bituminous mixes endorse the possible use of bottom ash in the binder course.

**Gunalaan Vasudevan (2013)** conducted a test on Performance characteristics of Bottom ash in HMA (Hot Mix Asphalt). The objective of this research is to use the Bottom ash as aggregates in sub bases, bases, and pavement layer. This research is motivated with three parts objectives for evaluating the stability of bitumen mixture which are prepared form certain percentage of bottom ash using Marshall Method, determining physical characteristics of bottom ash when it was mixed with bitumen and evaluated the improvement of engineering properties of the Marshall cube in terms of texture and appearance.

Based on the experimental results, the sample with bottom ash is superior to conventional samples in terms of stiffness, strength and the sample flow. Subsequently, the pavement will become stronger and can withstand if loaded high traffic load. However, there are drawbacks with the usages of coal bottom ash as mineral filler where the air void content increased which cause in reduction of density in the mixture.

**Tons et al. (1991)** the purpose of his study is to investigate the feasibility of using fly ash as an asphalt extender and to study the effect of fly ash particle size and other variables on the replacement process.

As far as this study shows, it is reasonable to replace up to 40 percent of asphalt volume with medium fly ash (1-44 $\mu$  in size) for dry climates; however, for moist climates the replacement should not exceed 30 percent.

**Sinha, A. K., et al. (2009)** conducted test on sub-soil for a proposed road construction of a 4 km with pond ash which is running from Kalindi Colony to Kalindi Kunj in New Delhi, India. Some field tests were conducted such as Standard Penetration Test (SPT) and Cone Penetration Test (CPT). Based on the laboratory experiments and field results, the design of pond ash embankment with and without berm was also done in two types of conditions *i.e.* steady seepage condition and sudden draw down with seismic factor.

It is observed that under the highest flood level with seismic effect, the fly ash embankment is exposed to both sudden draw down and steady seepage conditions.

**Ali, N., et al. (1996)** conducted experimental study to observe the outcome of fly ash on the mechanical properties of bituminous mixtures. It was also evaluated the significant effect of using fly ash in improving performance characteristics and modifying pavement distress. In this study, four types of specimens with various percentage of fly ash fractions were studied. The properties such as permanent deformation, resilient modulus, creep and fatigue were calculated at three different temperatures. Moisture induced damage tests were also carried out to assess moisture induced damage. The pavement performance was predict by VESYS model.

Results indicated that fly ash as a mineral filler can be used to increase resilient modulus characteristics and stripping resistance. The addition of fly ash did not reduce field performance of asphalt concrete mix in terms of rut depth and serviceability index but with the increase in temperature the sum of surface cracking is also increased in the pavement.

**Boyes, Anthony John. (2011)** studied the possible effect of fly ash as a mineral filler in asphalt mixes can aid in reinforcing and reducing bituminous moisture induce damage. The anti-stripping effect of two waste product cement kiln dust (CKD) and fly ash was investigated by compared them with hydrated lime and an amine-based chemical additive.

The observation shown that class C fly ash can be used as an anti-stripping additive in asphalt mix; however it is expensive than amine chemicals or lime. Also, test performed with dynamic shear rheometer show that fly ash additives have a effect to stiffen the asphalt binder. Overall, 5% class C fly ash and 1.5% hydrated lime treated specimens demonstrated the greatest overall resistance to moisture damage. Combinations of 5% and 7% class C fly ash and 1.5% and 2% lime were determined to have significantly higher conditioned compressive strengths than control.

**Partl, Manfred, K. Sokolov, and H. Kim. (2008)** conducted Laboratory study on a special type of carbon fiber grid which was placed at different depth in asphalt pavements. The purpose of the study was to obtain the design information about the position of the grid which will give optimum result. Two different types of asphalt pavements were examined (a) asphalt concrete and (b) mastic asphalt.

This study reveals that with addition of carbon grid stiffness, failure strain and stress, and resistance against low temperature cracking increased. However, during rutting tests with Model Mobile traffic Load Simulator (MMLS) it was found that the grid was not able to improve resistance against flow value in the mastic asphalt layer.

**Hadiwardoyo, Sigit Pranowo (2013)** studied that the failure at the surface layers of road is due to the change in temperature and the load of the traffic. Structural. He performed an experiment on Short coconut fibers in bitumen mix. He execute the experiment with various percentage of coconut fibers ranging from 0.5% to 1.50% with the increment of 0.25%. The fiber size was also varied with 5mm, 7.5mm, 10mm, and 12.5 mm. He test the bitumen characteristic with coconut fibers.

From the result obtained in Marshall properties test he found that the Marshall stability increased by 10-15%, when 0.75% of fiber content and 5-mm of fiber length was added by weight of the mixture. He also observed that with the addition of fiber in bitumen, change the bitumen property with a lower penetration value.

**Putman, Bradley J., and Serji N. Amirkhanian (2004)** studied the use of waste fiber in stone mastic asphalt mixture (SMA). He used waste tire and carpet fibers as an additive to stabilizing the excessive drain-down due to relatively high air void in SMA. He also studied the performance characteristics of SMA mixtures prepared with waste tire and carpet fibers. A comparative study has been done between SMA modified with tire and carpet fibers and with other mixes prepared with cellulose and polyester.

From the observation he found that the sample containing carpet and tire fibers, were effective in stopping unnecessary drain-down of the SMA mix. The toughness of the SMA mixes increases when added with tire and carpet fibers as compared to other cellulose fibers. The mix comprising tire fibers did not lose any toughness when conditioned in water. The resistance to moisture induced damage of the bituminous mixes, which contained tire and carpet fibers 100.9 and 101.8%, respectively.

**Kumar, Pawan, Satish Chandra, and Sunil Bose (2007)** studied the performances of the SMA mixture modified with crumb rubber modified binder (CRMB) and low viscosity binder coated jute fibers. The performance of SMA mixture were assessed by conducting two different methods of drain-down, durability test, moisture susceptibility test, fatigue life tests and rutting test. He also compared the characteristic of modified SMA prepared with coated jute fiber and with other patented fibers.

From the test observation he conclude that fiber content of 0.3% by weight of the mix improve the Drain-down property of the mix. Also in moisture susceptibility test the mixture shows satisfactory result. The observation from Hamburg wheel tracking tests, aging tests and flexural fatigue tests carried out on three mixes of SMA indicate better result than conventional mix.

**Kar, Debashish (2007)** studied the effect of indigenously available sisal fiber on SMA and BC mixture. He considered sisal fiber as an additive for BC mix and stabilizing agent for SMA mix. Fiber content varied from 0% to 0.5% by weight of total mix whereas binder content was varied

from 4% to 7%. For mineral filler he used fly ash, as it has shown satisfactory result at the initial stage of experiment. For the performance test the BC and SMA mixes were subjected to various test such as Drain down test, Static Creep test and Static Indirect Tensile Strength Test.

From the Marshall properties test it was observed, addition of fiber helps to improve the Marshall Stability and indirect tensile strength, it also reduces the Drain down. He again observed that the indirect tensile strength of SMA mixture is better than BC mixture. From Marshall test he found that the optimum binder content for BC and SMA were 5% and 5.2% respectively whereas optimum fiber content were 0.3%.

## **2.2 Summary**

1. From the literature study it is clear that the bituminous mixes that are prepared with bottom ash has delivered satisfactory result in term of performance characteristics, while in Marshall properties analysis it has shown some draw backs in the ground of high air void and reduced density of mixture.
2. Besides this, the study of using of bottom ash and fly ash (coal ash) together in the bituminous mix were not yet found, which is the main motivation of this research work.
3. Again the use of fiber is limited to SMA and BC due to its comparatively high air voids content. Hence in many research work fibers are used as an additive or as a stabilizing agent in SMA or BC.

# CHAPTER 3

## RAW MATERIALS

---

### 3.1 Mixture constituent

A bituminous mix is made from aggregate, graded from maximum fraction to smaller fraction (usually less than 25mm IS sieve to the mineral filler, smaller than 0.075mm IS sieve), which are blended with bitumen binder to form a consistent mixture. This mixture is then laid and compacted to achieve an elastic body which is seamlessly impervious and hard. The study of mix design is to attain the suitable proportion of aggregate, bitumen and other additives if added.

#### 3.1.1 Aggregates

Aggregates play an important part in bituminous mix. Maximum aggregate by weight of mixture is added to take the maximum load bearing & adding strength characteristics to the mixture. Hence, the physical properties and quality of the aggregates are considerably important to pavement. There are three types of mineral aggregates used in bituminous mixes, which are given below.

#### Coarse aggregates

Aggregates which are retained on 4.75 mm IS sieve are called as coarse aggregates. A good quality coarse aggregate should have physical characteristic like hardness, angular in shape, toughness, durability, free from dust particles, clay, vegetation and organic matters. Aggregate with these above physical properties offers quite good compressive strength and shear strength and shows good interlocking characteristic.

#### Fine aggregates

Aggregates size ranging from 4.75 mm to 0.075 mm IS sieve are called Fine aggregates. As with coarse aggregate, Fine aggregate should be free from dusts, clay, vegetation, loam or organic matter. Fine aggregate fills the voids between the coarse aggregate and stiffens the binder.



## **Mineral Filler**

Aggregates those are smaller than 0.075 mm IS sieve is called as mineral filler. Filler are used to fills the voids in mix, which cannot be filled by fine aggregates. And also used to increase the binding property between the aggregates in the preparation of specimens.

### **3.1.2 Bitumen**

Bitumen is essential in bituminous mix because of its visco-elastic and adhesive property. It binds the aggregate and fills the small voids which offers impermeability in mixture. At low temperature it acts like an elastic body and at high temperatures it behaves like a viscous liquid [22].

### **3.1.3 Additives**

Additives are used in the mixture to provide better strength characteristic and engineering property. Now a days different additives such as fibers, polyethylene, minerals, polyester etc. are added either to stabilize or to improve performance property of the pavement.

### **3.1.4 Bitumen Emulsion**

A bitumen emulsion is two phase system in which a significant amount of finely divided bitumen is suspended over an aqueous medium and stabilized by one or more suitable material. When the bitumen emulsion is applied on aggregate, it breaks down and start binding the aggregate. The first sign of break down occur when the color of bitumen emulsion film change from chocolate brown to black. Bituminous emulsion are especially used in patch and maintenance work [22]. Three types of emulsion are there i.e. (i) Rapid setting (RS), (ii) Medium setting (MS), and (iii) Slow setting (SS)

## **3.2 Materials used in study**

In this study following materials are taken in to consideration to prepare the bituminous mix.

- Stone chips (as coarse aggregate)
- Bottom ash (as fine aggregate)
- Fly ash (as mineral filler)

- VG-30 (as bitumen binder)
- Sisal fiber (as additives)
- SS-1 emulsion (as fiber coating agent)

### 3.2.1 Aggregate

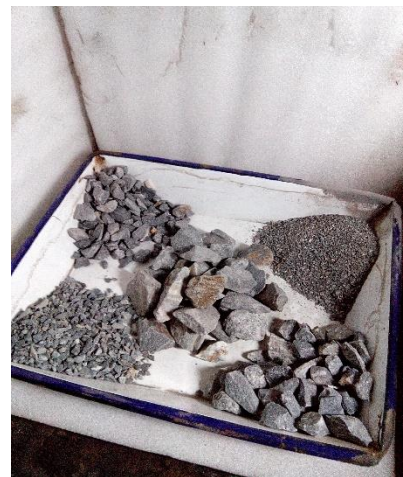
Coarse aggregates comprised of stone chips were procured from a nearby crusher and were stored by sieving in to different sizes. For this study, stone chips comprising coarse aggregate fractions and upper size fractions of fine aggregates ranged from 26.5 mm to 0.3 mm were used as shown in Figure 3.3. For lower fractions of fine aggregates and mineral filler, bottom ash and fly ash were respectively used to the extent of 9% and 5% by weight of total mix. Bottom ash was procured from the nearby NSPCL thermal power plant (shown in Figure 3.2), while fly ash was collected from the nearby Adhunik Metaliks Power plant (shown in Figure 3.1). The physical properties of coarse aggregates and fine aggregates which are primarily required for paving are given in Table 3.1.



**Figure 3.1 Fly ash**



**Figure 3.2 Bottom ash**



**Figure 3.3 Stone chips**

**Table 3.1 Physical property of coarse aggregate and fine**

Property	Code specification	Test Result	
		Natural Aggregate	Bottom ash
Aggregate impact value, %	IS:2386 part-IV	14	-
Aggregate crushing value, %	IS:2386 part-IV	13.5	-
Los Angles Abrasion test, %	IS:2386 part-IV	18	-
Soundness test (five cycle in sodium sulphate), %	IS:2386 part-V	3	8.2
Flakiness index, %	IS:2386 part-I	11.9	-
Elongation index, %	IS:2386 part-I	12.5	-
Water absorption, %	IS:2386 part-III	0.14	10.75
Specific gravity	IS:2386 part-III	2.7	2

### 3.2.2 Bitumen

The paving bitumen grade VG-30 (VG-viscosity grade) was used in this experimental study. Initially, two bitumen grades such as VG-30 and VG-10 were used to study the Marshall characteristics of mixes with the materials considered. These initial trials resulted better Marshall characteristics, especially the Marshall stability in respect of mixes made up of bottom ash, fly ash and emulsion coated fiber with VG-30 bitumen as binder. The physical characteristics of VG-30 bitumen tested as per IS standards are given in Table-3.2.

**Table 3.2 Physical property of binder.**

Physical Properties	IS Code	Test Result
Penetration at 25°C/100gm/5s, 0.01mm	IS:1203-1978	46
Softening Point, °C	IS:1205-1978	46.5
Specific gravity, at 27°C	IS:1203-1978	1.01
Absolute viscosity, Brookfield at 160°C, Centi Poise	ASTM D 4402	200

### 3.2.3 Additives (Sisal Fiber)

The sisal fiber, a naturally and locally available product has been used as a modifier for improving the engineering properties of conventional DBM mixtures. In this experimental work sisal fibers were coated with slow setting emulsion (SS-1) and stored at 110°C in hot air oven for 24hrs. Emulsion coating was considered considering the organic nature of the material. Sisal fiber is a cellulose fiber having soft yellowish color. The sisal fiber used in this study is shown in Figure.3.4 (a). It is durable, anti-static and recyclable [13]. The physical and chemical property of sisal fiber are given in Table -3.3.



Figure 3.4 (a) Sisal fiber used.



Figure 3.4 (b) Sisal fiber plant [15]

Table 3.3 Physical and chemical property of sisal fiber[13].

Chemical composition	
Composition	Test result
Cellulose, %	65
Hemicellulose, %	12
Lignin, %	9.9
Waxes, %	2
Physical property	
Property	Test result
Density, gm/cc	1.51
Tensile strength, MPa	510-640
Young's modulus, MPa	9.5-2.0
Elongation at break, %	2.0-2.5

### **3.2.4 Emulsion (SS-1)**

SS-1 is an anionic based slow setting bitumen emulsion, which is extensively used for tack coat, fog seal, dust control, and in fine graded mix. Slow setting emulsions are the steadiest emulsions, which usually can be diluted with water and mixed with aggregates and mineral fillers and for all paving uses. To allow the emulsion to fully cure, the pavement temperatures at construction should be sufficiently high [12]. The percentage residue content in SS-1 emulsion is found to be 71.48% in 100ml of emulsion by residue evaporation method mentioned in IS 8887 (2004)

# CHAPTER-4

## EXPERIMENTAL WORK

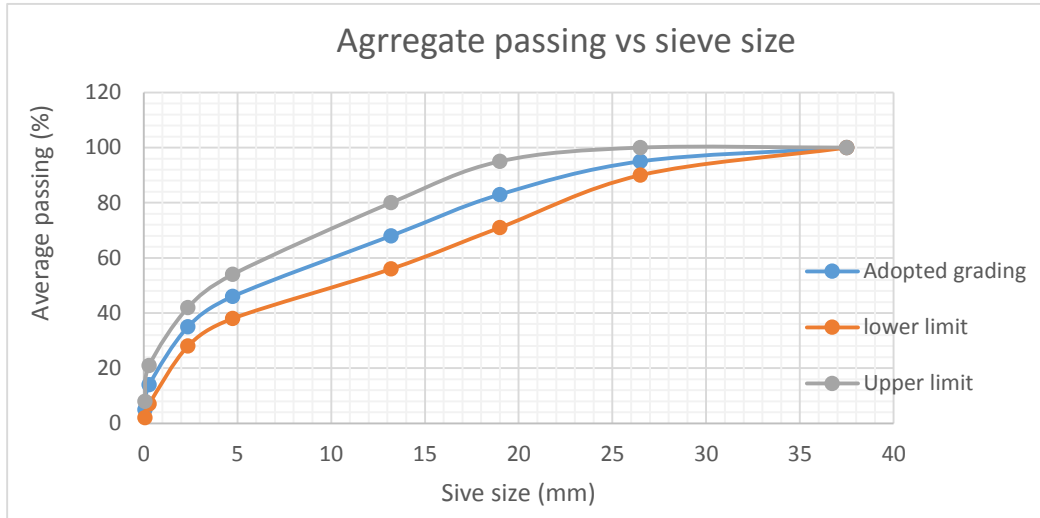
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### 4.1 Experimental Design

The adopted gradation for DBM sample has been considered as specified in MORTH (2013) and is given in Table-4.1. Throughout the experimental study the aggregate gradation given in Table4 was followed, and the following tests were performed. The aggregate gradation curve is shown in figure.4.1.

**Table 4.1 Gradation of aggregate.**

Sieve size (mm)	Adopted gradation (% Passing)	Specified limit (as per MORTH, 2013) (% Passing)	
37.5	100	100	Natural aggregate
26.5	95	90-100	
19	83	71-95	
13.2	68	56-80	
4.75	46	38-54	
2.36	35	28-42	
0.3	14	7-21	Bottom ash
0.075	5	2-8	Fly ash



**Figure 4.1 Aggregate gradation curve.**

After adopting the above aggregate gradation the subsequent test were made to ensure the performance characteristics.

- *Marshall test of mixes to evaluate volumetric analysis*
- *Static indirect tensile test*
- *Resistance to moisture damage (Tensile strength ratio)*
- *Retained stability test*
- *Static creep test*

## 4.2. Design mix

The DBM mixtures were prepared in accordance with the Marshall procedure specified in ASTM D6927-2015. All ingredients of mixture, such as coarse aggregates, fine aggregates, filler, fiber and VG-30 bitumen were mixed in a specified procedure. Before preparing the samples, fibers were coated with SS-1 emulsion and stored in a hot air oven at 110°C as shown in Figure 4.3. Coated fiber are stored for 24 hours to ensure proper coating around each fiber and to drain down extra bitumen that may adhere to fiber, as shown in Figure 4.3 [26 and 27]. Then the fibers were cut into specified lengths of about 5mm, 10mm, 15mm and 20mm as given in figure 4.4. The aggregates and bitumen were heated separately to the mixing temperature of 155°C to 160°C. The temperature of the aggregates was maintained 10°C higher than that of the binder. Required



quantities of bitumen VG-30 and coated emulsion fiber pieces were added to the pre-heated aggregates and thoroughly mixed as shown in Figure 4.5.



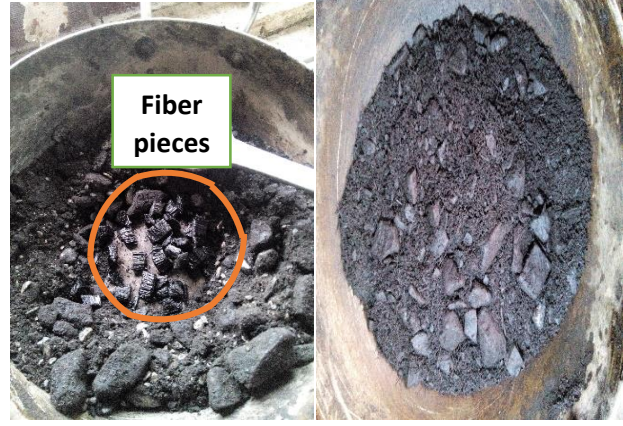
**Figure 4.2 Coating of emulsion on fiber.**



**Figure 4.3 Oven dry coated fiber.**



**Figure 4.4 Cutting of coated fiber.**



**Figure 4.5 Addition and mixing of fiber**



(a)



(b)



(c)



(d)

**Figure 4.6**

**(a) Pouring of mixture in mould, (b) Compaction of mixture in progress, (c) DBM samples, (d) Marshall test in progress**



The quantity of binder to be added was calculated from subtracting the weight of emulsion coated fiber from weight of design binder. Proper mixing was done manually till the colour and consistency of the mixture appeared to be uniform. The mixing time and temperature was maintained within 2-5 minutes and 150<sup>0</sup>C-160<sup>0</sup>C respectively. The mixture was then poured in to a pre-heated Marshall mould and compacted using Humboldt Automatic Marshall Compact with 75 compaction blows on each side. The specimens were kept 24 hours for cooling to a temperature of 25±1<sup>0</sup>C (as shown in Figure 4.6 (a), (b), (c) respectively).

In this experiment, the resistance to deformation of a Marshall cylindrical specimen of DBM mixture is measured. The specimen is loaded diametrically at a deformation rate of 50 mm/min as shown in Figure 4.6(d). Here are two major features of the Marshall method of mix design are given below.

1. Stability and flow values
2. Voids analysis.

The Marshall stability for bituminous mix is defined as the maximum resistance carried by specimen at a standard temperature of 60°C. The flow value is recorded when the specimen deformed under maximum. The Marshall voids analysis were done before the Marshall stability test. In this voids analysis bulk specific gravity ( $G_{mb}$ ), air voids (VA), voids in mineral aggregate (VMA), voids filled with bitumen (VFB), and Marshall Quotient were determined, that are discuss in next chapter.

### **4.3 Static indirect tensile test**

Static indirect tensile test of bituminous mixes was performed in accordance to ASTM D 6931 (2007) to assess the resistance to thermal cracking for a Marshall cylindrical specimen that is loaded in vertical diametrical plane as shown in figure 4.7. This tests were carried out on DBM specimen which were prepared at their optimum binder content, optimum fiber content and optimum fiber length as calculated from Marshall propeties analysis. The effect of temperature on the Indirect Tensile Strength (ITS) of mixes with and without fiber was also studied. The load at

which tensile crack were develop in the specimen were noted down from the dial gauge of the proving ring and was calculated.



**Figure 4.7 Loading and failure pattern of indirect tensile strength test.**

$$S_t = \frac{2000 \times P}{\pi \times D \times T} \quad \dots (1)$$

Where  $S_t$  = Indirect Tensile strength, kPa

$P$  = Maximum Load, kN

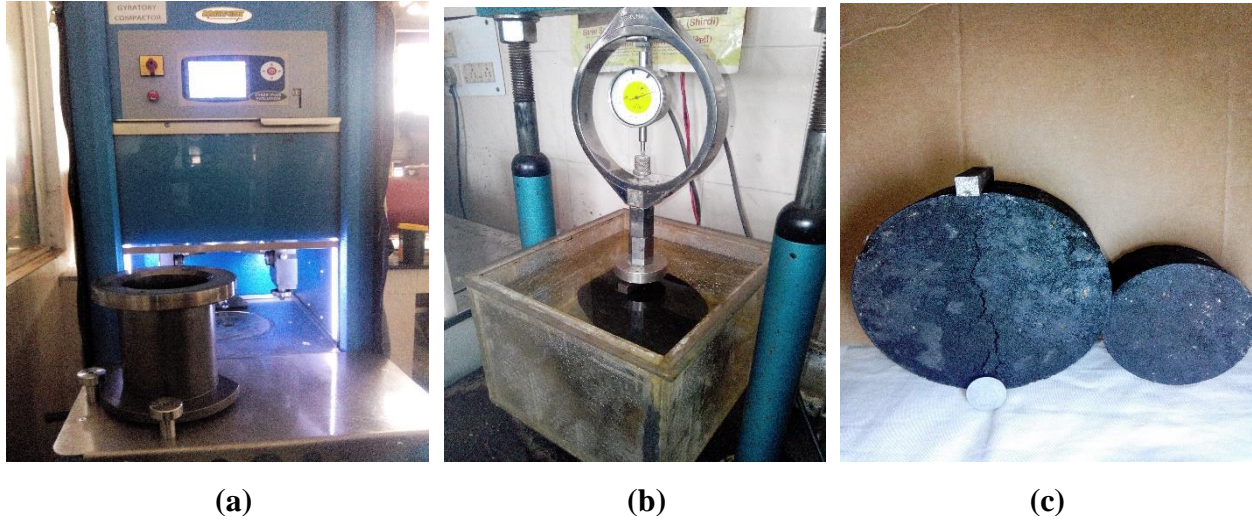
$T$  = Specimen height before testing, mm

$D$  = Specimen Diameter, mm

The test temperature was varied from 5<sup>0</sup>C to 40<sup>0</sup>C at an increment of 5<sup>0</sup>C. The average tensile strength of three sample was reported.

#### **4.4 Resistance to moisture damage (Tensile Strength Ratio (TSR))**

The resistance to moisture susceptibility of bitumen mixes were measured by tensile strength ratio. The test is similar to Static Indirect Tensile test only the specimen were prepared in gyratory compactor with 7% air void and 150 mm diameter to 62.5 mm height specimen dimension as shown in figure 4.8. Six sample of equal avg. air void was prepared and divided into two subset. One subset was partially saturate to be moisture conditioned with distilled water at room temperature using a vacuum chamber by applying a partial vacuum of 70 kPa or 525 mm Hg (20 in. Hg) for a short time such as five min. after that the partially saturated samples are cured to be moisture conditioned in distilled water at 60±1.0°C for 24 hour.



**Figure 4.8**

**(a) Sample Prepared in gyratory compactor, (b) Moisture susceptibility test in progress, (c) Failure cracks in DBM sample**

The dry subset was cured in water bath for 20 min at  $25 \pm 1.0^\circ\text{C}$  while the temperature of moisture-conditioned subset was adjusted to  $25 \pm 1^\circ\text{C}$  by soaking it in water bath for 1 hour prior to testing. The test was conducted in accordance with the ASTM D4867/D4867M – 09. The tensile strength ratio of conditioned and unconditioned subset was determined by the equation 2 given below. The average result for TSR value should be minimum 80%, failing to this the sample were considered as damage.

$$\text{Tensile strength ratio (TSR)} = \frac{S_{tm}}{S_{td}} \times 100 \quad \dots (2)$$

Where, TSR= tensile strength ratio, %

$S_{tm}$  = average tensile strength of the moisture-conditioned subset, kPa,

and,  $S_{td}$  = average tensile strength of the dry subset, kPa.

#### **4.5. Retained stability test**

The loss of stability in bituminous mixes due to penetration of moisture are measure in the form of Retained stability test. This test also shows the sign of percentage stripping of bitumen from aggregate. The test was conducted in accordance with the STP 204-22 with standard Marshall

Samples, prepared according to the Marshall procedure specified in ASTM D6927-2015. Six specimen were prepared with 4% air void and divided into two subset. Each of the subset were conditioned with water at  $60 \pm 1^{\circ}\text{C}$  for half an hour and 24 hours and tested in accordance to Marshall stability test. A minimum of 75% retained stability is required as per MORTH-2013 to claim the mixture can with stand moisture.

$$\text{Retained stability} = \frac{S_2}{S_1} \times 100 \quad \dots (3)$$

Where,  $S_1$ = Unconditioned stability, kN

$S_2$ = Conditioned stability, kN (after conditioned 24 hours at  $60^{\circ}\text{C}$  in water bath)

#### **4.6 Static creep test**

This test method is used to determine the resistance to permanent deformation of bituminous mixtures at specific temperatures. For Static Creep test sample were prepared at their optimum binder content, optimum fiber content and fiber length. The test was conducted as per Texas department of transportation (2005) specification. The specimens were placed in a hot air oven maintained at a temperature of  $40^{\circ}\text{C}$  for three to five hours prior to start of the test. Then 125 lb. (556 N) load was applied for one hour followed by 1 min initial loading rest. This allows the loading platens to achieve more uniform contact with the specimen. The deformation was registered in each 5 min intervals starting from 0 min to 60 min by using a dial gauge graduated in units of 0.002 mm. After then the load was removed and its recovery was registered up to next 5 min at 1 min intervals. A graph has been plot between time and deformation.

# CHAPTER 5

## ANALYSIS OF RESULTS AND DISCUSSION

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### 5.1 Introductions

This chapter deals with results analysis and discussion for test that are carried out for DBM sample in previous chapter. This chapter is divided into three sections. In first section the parameter and the equation used for Marshall properties analysis are given below. Second section deals with calculation and comparison of optimum binder content, optimum fiber content and optimum fiber length of DBM mixes with and without coal ash used as fine aggregate and filler. Third section deals with analysis made from the experiment such done in previous chapter static indirect tensile, static creep test at 40<sup>0</sup>C, moisture susceptibility test (Tensile strength ratio), and retained stability test.

### 5.2 Parameters used in the study

All the Marshall propeties properties were calculated as per Das A. and Chakraborty P. (2010). The concern equation and other formulae used in calculations are given below.

#### 1. Bulk specific gravity of aggregate (G<sub>sb</sub>)

$$G_{sb} = \left[ \frac{M_{agg}}{\text{Volume of (mass of agg+air void in mix+absoeved bitumen)}} \right] \quad \dots (4)$$

Where Magg = Mass of aggregate

#### 2. Effective specific gravity of aggregate (G<sub>se</sub>)

$$G_{se} = \left[ \frac{M_{agg}}{\text{Volume of (mass of agg+air void in mix)}} \right] \quad \dots (5)$$

$$\text{Or, } G_{se} = \left[ \frac{(M_{mix} - M_b)}{\left( \frac{M_{mix}}{G_{mm}} - \frac{M_b}{G_b} \right)} \right] \quad \dots (6)$$

Where,  $M_{agg}$  = mass of aggregate

$M_b$  = mass of bitumen used in mix

$G_b$  = specific gravity of bitumen

### 3. Apparent specific gravity ( $G_a$ )

$$G_a = \left[ \frac{M_{agg}}{\text{Volume of aggregate}} \right] \quad \dots (7)$$

### 4. Theoretical maximum specific gravity of mix ( $G_{mm}$ )

$$G_{mm} = \left[ \frac{M_{mix}}{\text{Volume of (mix-air void)}} \right] \quad \dots (8)$$

### 5. Bulk specific gravity of mix ( $G_{mb}$ )

$$G_{mb} = \left[ \frac{M_{mix}}{\text{Bulk volume of mix}} \right] \quad \dots (9)$$

### 6. Air voids ( $V_A$ )

$$V_A = 1 - \frac{G_{mb}}{G_{mm}} \times 100 \quad \dots (10)$$

### 7. Voids in mineral aggregates ( $VMA$ )

$$VMA = \left[ 1 - \frac{G_{mb}}{G_{mm}} \times P_s \right] \times 100 \quad \dots (11)$$

Where,  $P_s$  = percentage of aggregate present by total mass of mix

### 8. Voids filled with bitumen ( $VFB$ )

$$VFB = \frac{VMA - V_A}{VMA} \times 100 \quad \dots (12)$$

### 5.3. Effect of coal ash (Bottom ash and Fly ash) on DBM mix

At the initial stage of experiment bottom ash and fly ash was used as fine replacement in DBM mix. In this experiment the total coal ash content is taken as 35% by weight of the total mix, from which the percentage of fly ash as mineral filler is fixed, *i.e.* 5% of weight of the mix. The bottom ash content is varied according to the DBM gradation specified in MORTH (2013), which is given in chapter 4.

#### 5.3.1 Marshall stability

It is seen from the figure 5.1 that using of coal ash in DBM mix is not satisfactory with respect to stability value, when compared with conventional mix. The maximum stability value of 11.83 kN was achieved when 14% of coal ash by weight of the mix was mixed for preparing DBM samples.

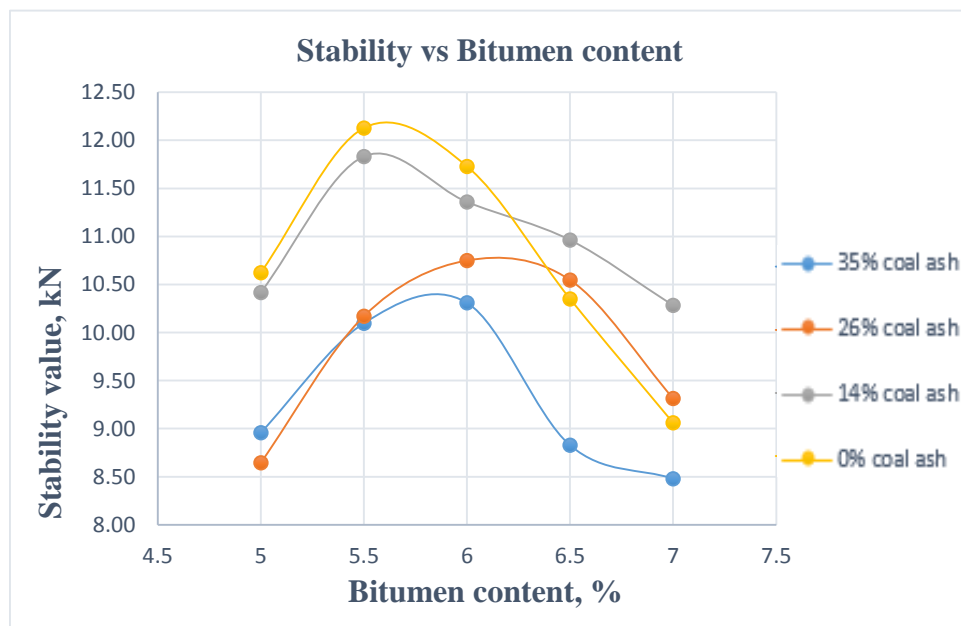
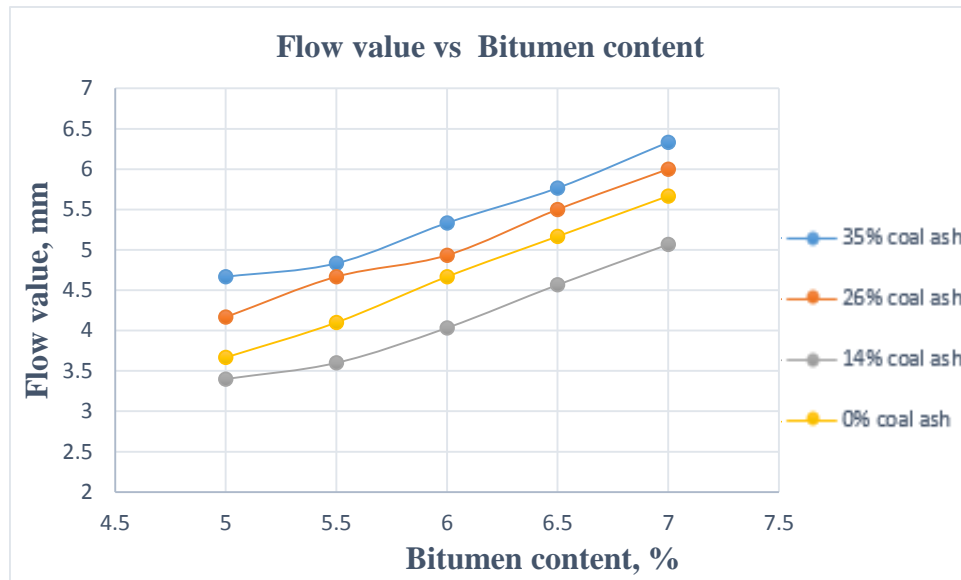


Figure 5.1 Variation of Stability value with bitumen content at different coal ash content

#### 5.3.2 Marshall flow value

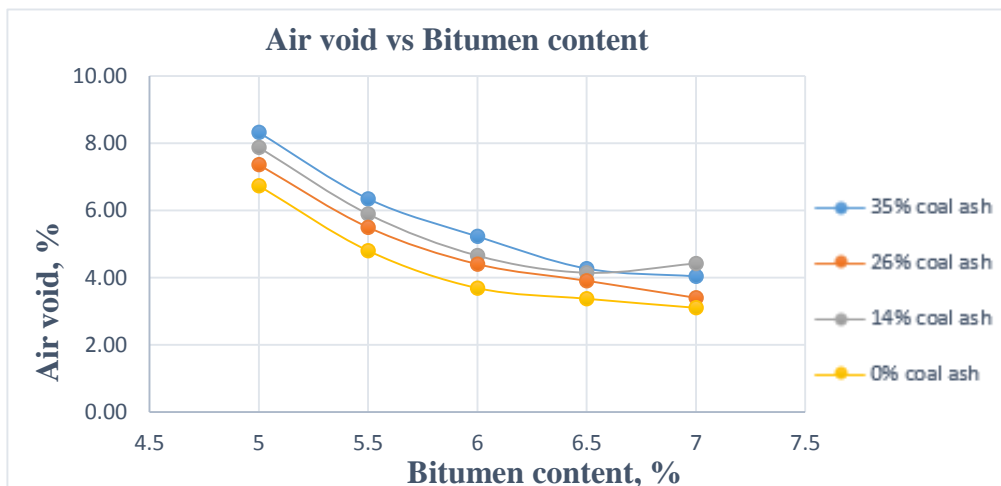
It was seen from the flow value vs bitumen content graph shown in figure 5.2 that with increase in bitumen content and Coal ash content the flow value increase. But with 14% coal ash content by weight of mix the flow value decrease as compare to the conventional mix.



**Figure 5.2 Variation of Flow value with bitumen content at different coal ash content**

### 5.3.3 Air void

It is observed from the graph shown in figure 5.3 that with increase in coal ash the air void increases. By taking 14% coal ash by weight of the mix, the air void is fairly near to the conventional mix, which means coal ash can be used with some modification to achieve optimum properties than conventional mix.

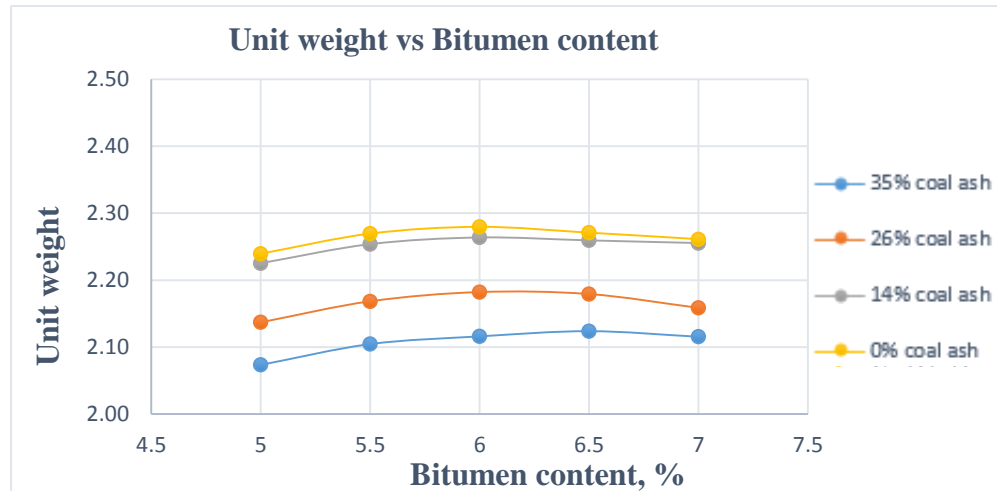


**Figure 5.3 Variation of Air void value with bitumen content at different coal ash content**



### 5.3.4 Unit weight

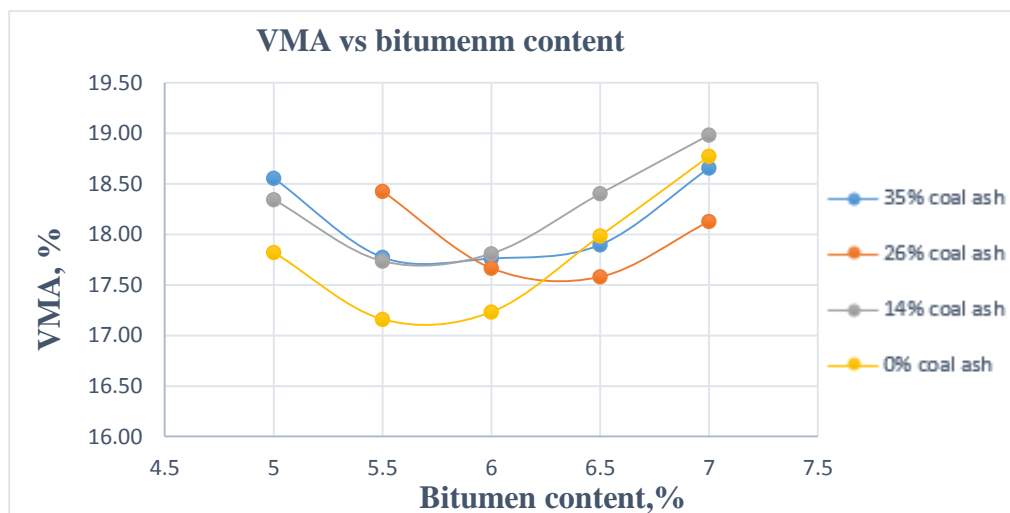
From the Unit weight and bitumen content graph shown in figure 5.4 it is observed that with increase in coal ash content the unit weight of DBM samples decreases. Coal ash been a lighter material cause the decrease of unit weight.



**Figure 5.4 Variation of unit weight value with bitumen content at different coal ash content**

### 5.3.5 Voids in Mineral Aggregate (VMA)

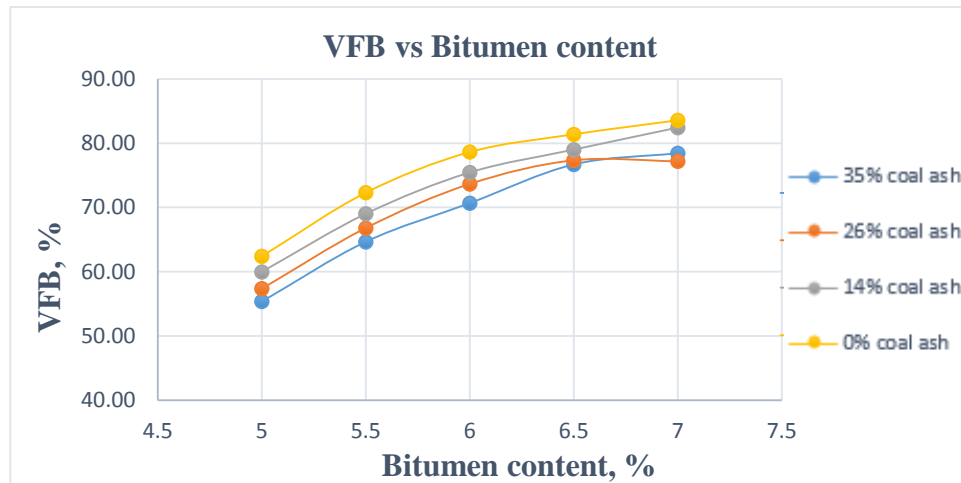
From the observation of VMA vs bitumen content graph in Figure 5.5, it is clear that with increase in bitumen content voids in mineral aggregate decrease rapidly first and then increases steadily.



**Figure 5.5 Variation of VMA value with bitumen content at different coal ash content**

### 5.3.6 Voids Filled with Bitumen (VFB)

It is observed from the VFB and bitumen content graph shown in Figure 5.6 that VFB increases rapidly with increase in bitumen and coal ash content.



**Figure 5.6 Variation of VFB value with bitumen content at different coal ash content**

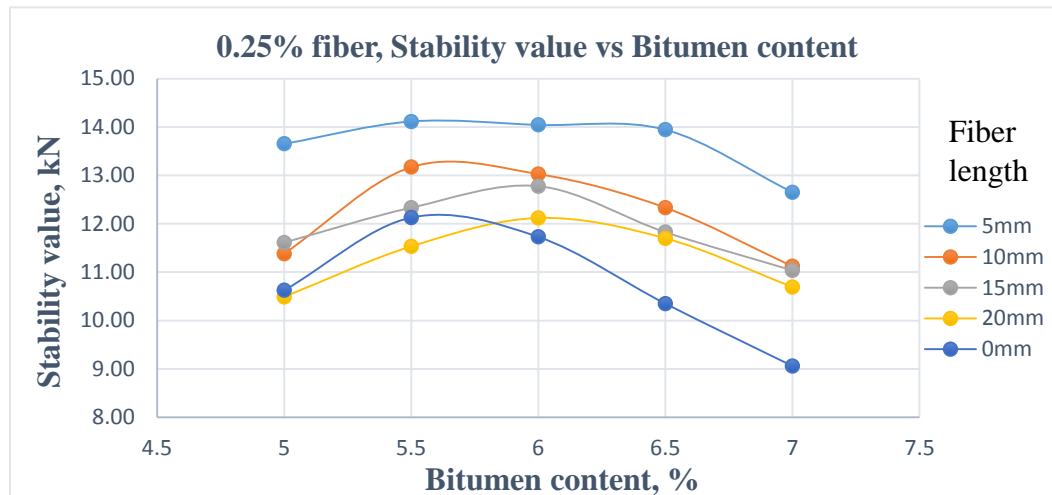
## 5.4 Effect of Sisal fiber and Coal ash (Bottom ash and Fly ash) on DBM mix.

From the above Marshall property of DBM mix that is prepared with coal ash, it is observed that, coal ash cannot deliver satisfactory result when used alone. The stability and flow values are not within the specification made for DBM mix. Also the volumetric analysis such as air void, unit weight, VMA and VFB, are lagging behind the conventional mix. Therefore the Marshall properties study is done by using coal ash and sisal fiber as an additive. The percentage of coal ash is taken as 14% as it shown better result than other coal ash content. The fiber content varied from 0% to 1% with 0.5% increment, along with fiber length ranging from 5mm, 10mm, 15mm, and 20mm.

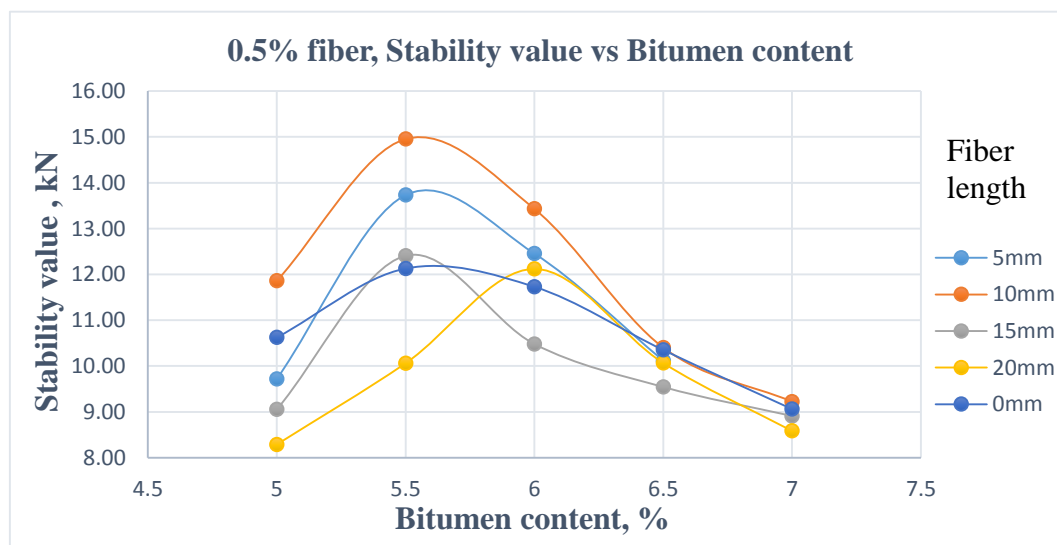
### 5.4.1 Marshall stability.

It is observed from the stability and bitumen content graph, shown in figure 5.7 to figure 5.10 that with increase in bitumen content and fiber content as well as fiber length the stability value increased to certain limit and then decreased. From the optimum binder content analysis it is found

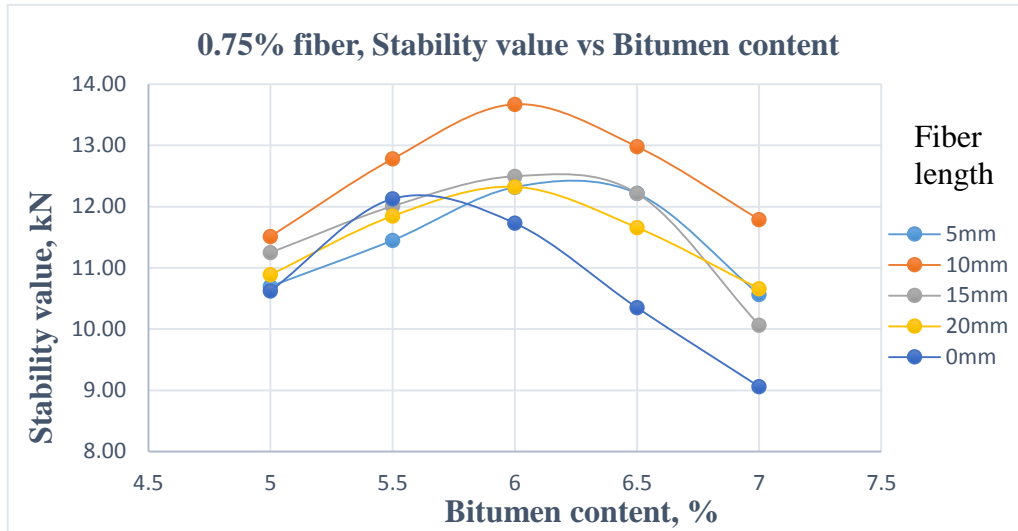
that the maximum stability of 15kn was achieved at an optimum binder content of 5.57% with optimum fiber content of 0.5% by weight of mixture along with fiber length of 10mm which was duly coated with SS-1 emulsion and cured for 24hours at  $110 \pm 1^\circ\text{C}$ .



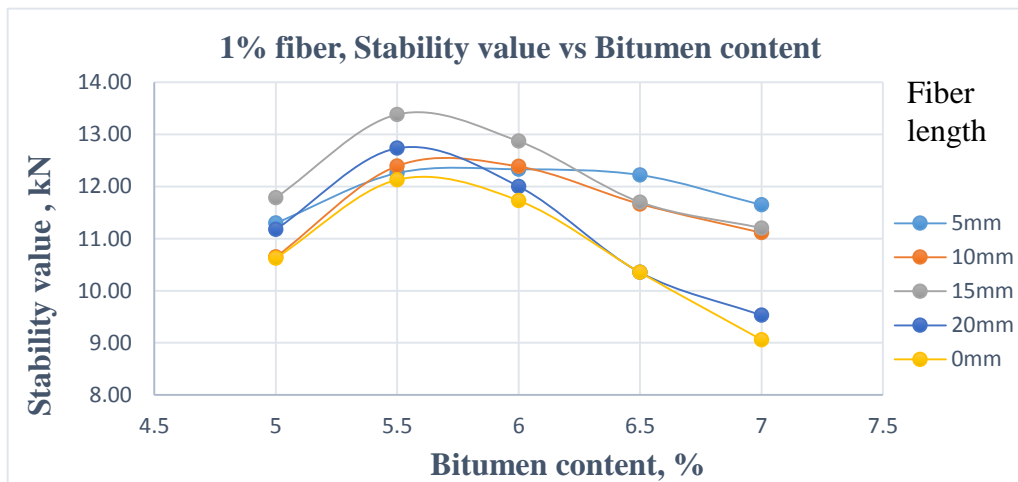
**Figure 5.7 Variation of Stability value with bitumen content in 0.25% fiber content at different fiber length**



**Figure 5.8 Variation of Stability value with bitumen content in 0.5% fiber content at different fiber length**



**Figure 5.9 Variation of Stability value with bitumen content in 0.75% fiber content at different fiber length**

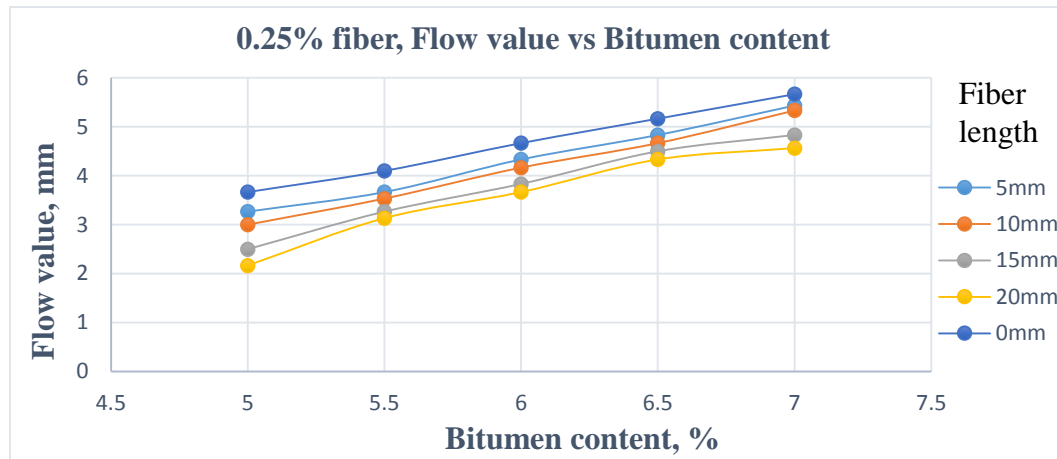


**Figure 5.10 Variation of Stability value with bitumen content in 1% fiber content at different fiber length**

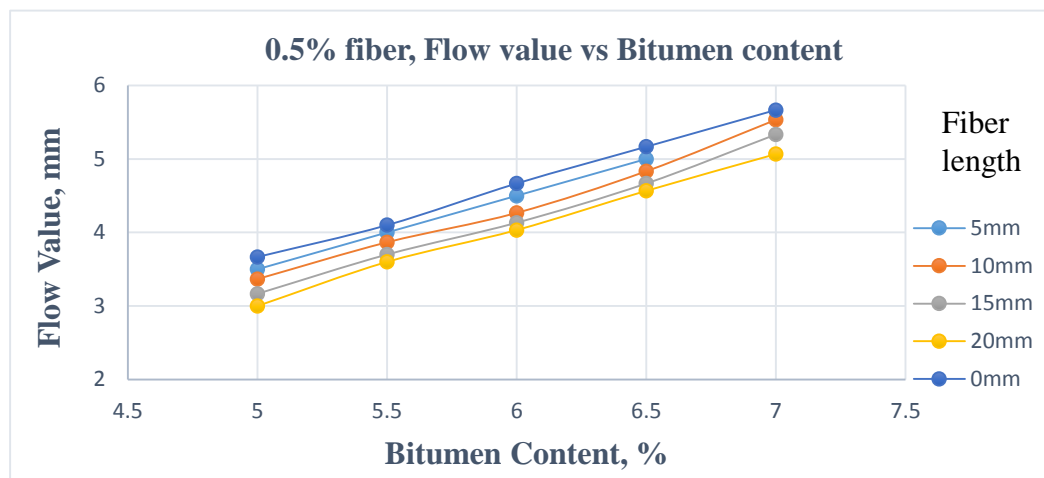
### 5.4.2 Marshall flow.

At the initial stage sample prepared with coal ash has shown increased flow value than the conventional DBM mix. But with the addition of sisal fiber the flow value decreased as shown in figure 5.11 to figure 5.14. The length of sisal fiber has significant influence on flow value. It is

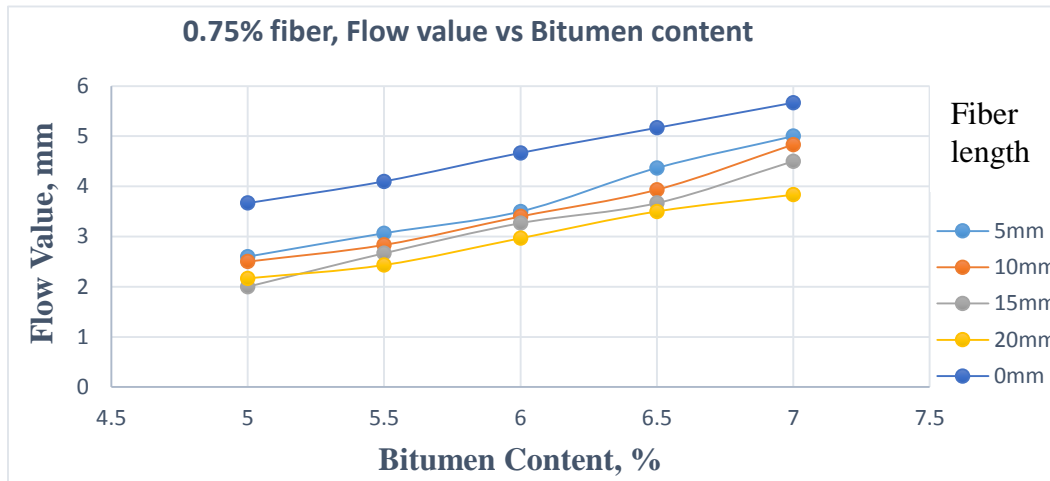
seen that with increase in fiber length flow value decreased, which is because of the stiffness of the mixture cause by adding sisal fiber.



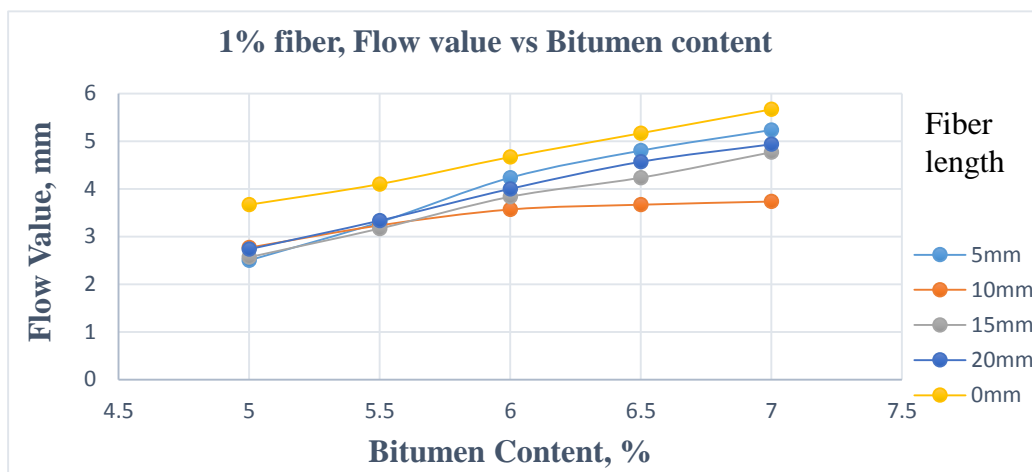
**Figure 5.11 Variation of Flow value with bitumen content in 0.25% fiber content at different fiber length**



**Figure 5.12 Variation of Flow value with bitumen content in 0.5% fiber content at different fiber length**



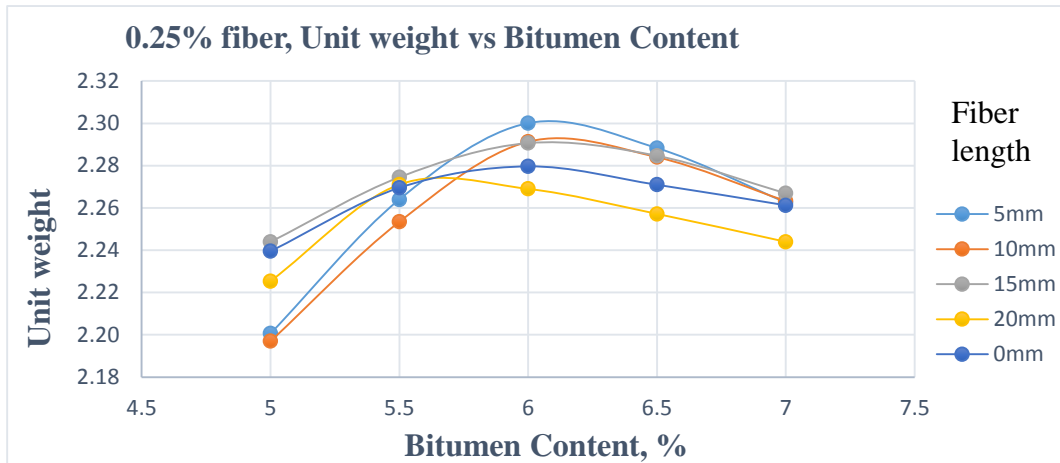
**Figure 5.13 Variation of Flow value with bitumen content in 0.75% fiber content at different fiber length**



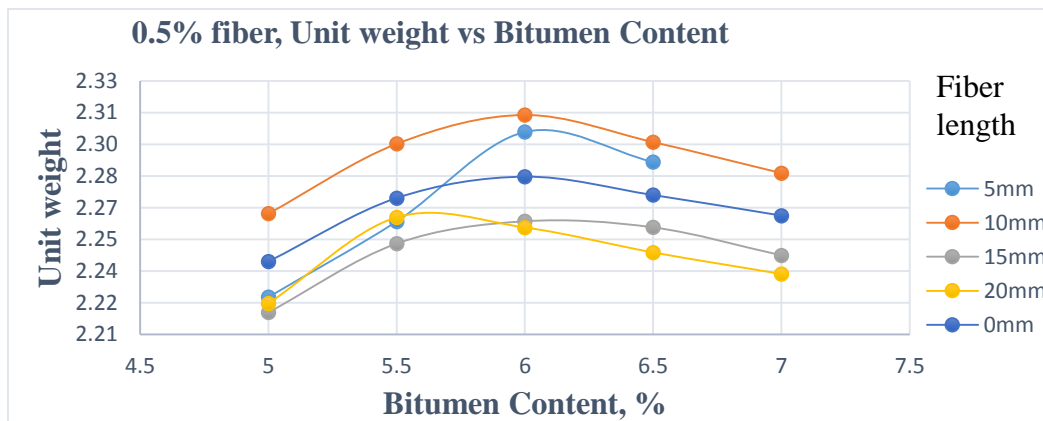
**Figure 5.14 Variation of Flow value with bitumen content in 1% fiber content at different fiber length**

### 5.4.3 Unit weigh

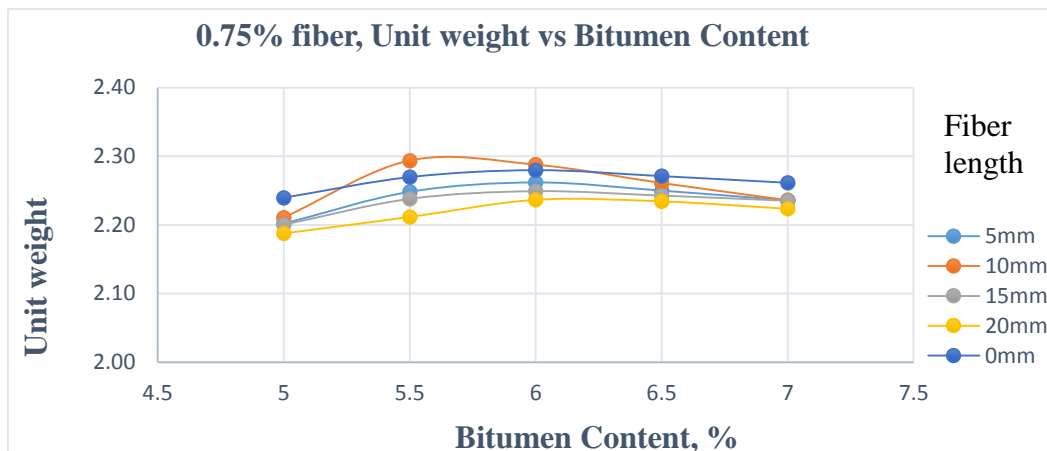
From the graph shown in figure 5.15 to figure 5.18 it is clear that with addition of fiber the unit weight decrease as compare to the conventional mix. It was also observe that not only addition of fiber but also coal ash reduced the unit weight too. This is because of both fiber and coal ash are lighter material than bitumen. The fiber content and fiber length has a significant effect on minimizing the unit weight.



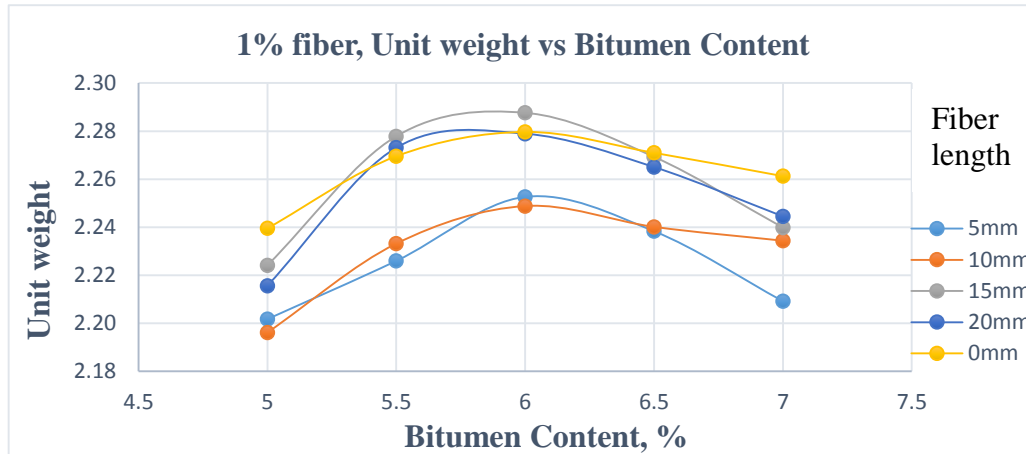
**Figure 5.15 Variation of Unit weight value with bitumen content in 0.25% fiber content at different fiber length**



**Figure 5.16 Variation of Unit weight value with bitumen content in 0.5% fiber content at different fiber length**



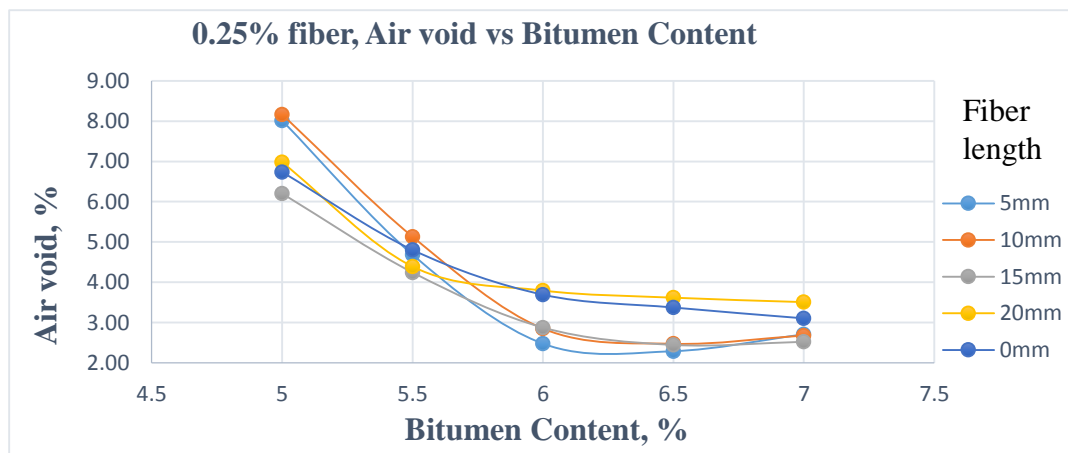
**Figure 5.17 Variation of Unit weight value with bitumen content in 0.75% fiber content at different fiber length**



**Figure 5.18 Variation of Unit weight value with bitumen content in 1% fiber content at different fiber length**

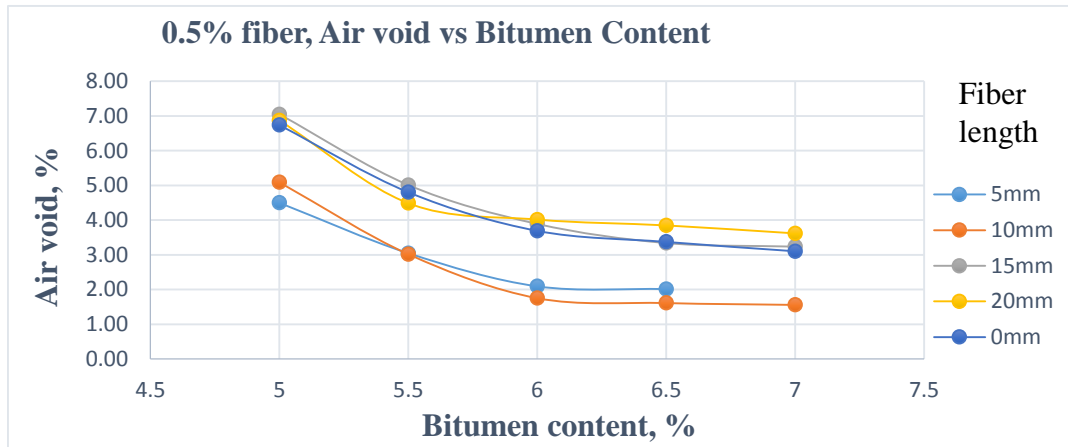
#### 5.4.4 Air voids

Generally DBM have HMA due to well graded aggregates. But at the initial stage of the study, the DBM sample prepared with coal ash have higher air voids in compare to conventional mix. Due to this reason sisal fiber is added to somewhat minimize the air voids. And as a result from the graphs shown in figure 5.19 to figure 5.22 it is clear that with increase in fiber content and fiber length the air void in the mixture decreases as compare to normal DBM mix. It has also observe that the air void was 14% less as compared to conventional DBM mix, when prepare with optimum coal ash content and optimum sisal fiber property.

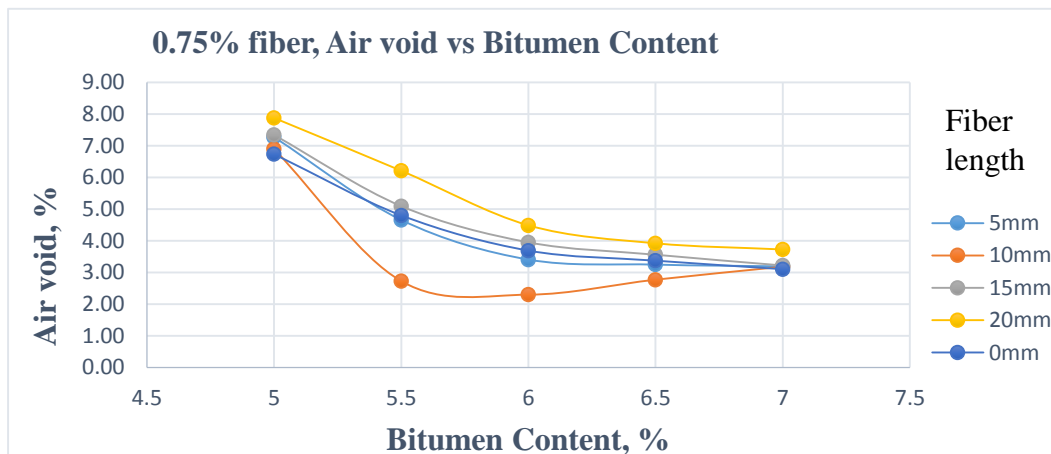


**Figure 5.19 Variation of Air void value with bitumen content in 0.25% fiber content at different fiber length**

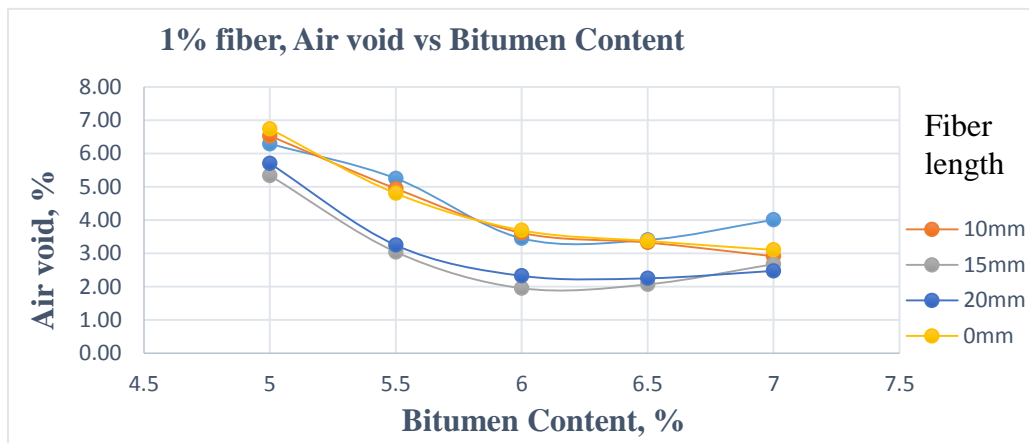




**Figure 5.20 Variation of Air void value with bitumen content in 0.5% fiber content at different fiber length**



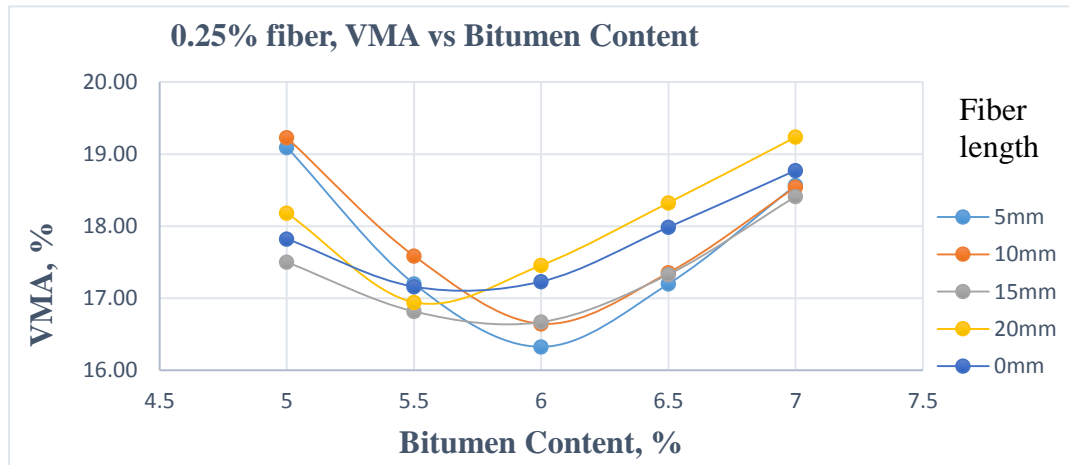
**Figure 5.21 Variation of Air void value with bitumen content in 0.75% fiber content at different fiber length**



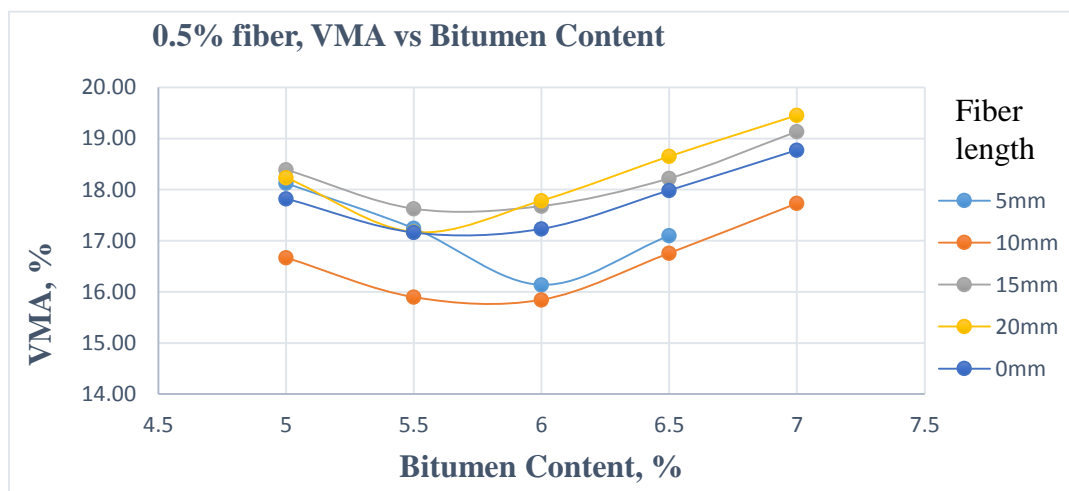
**Figure 5.22 Variation of Air void value with bitumen content in 1% fiber content at different fiber length**

### 5.4.5 Voids in mineral aggregate (VMA)

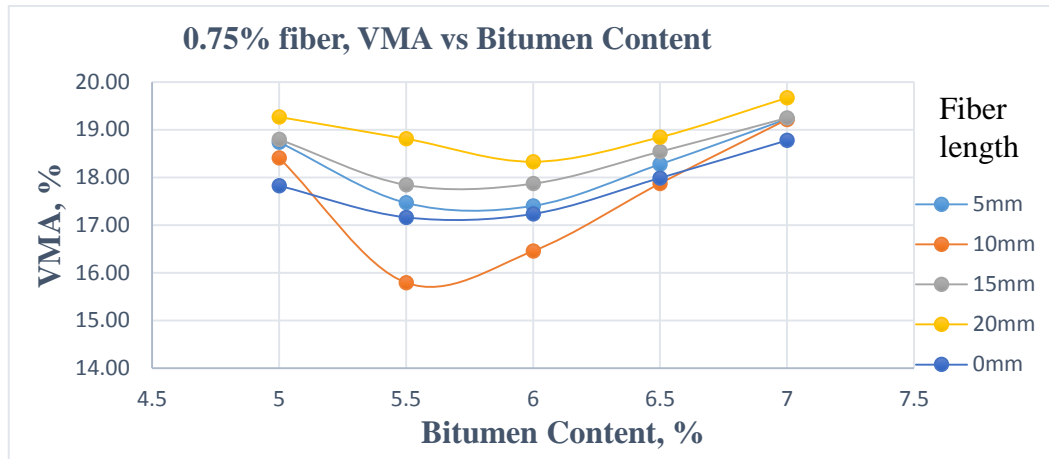
It is observed from VMA and bitumen content graph, shown in figure 5.23 to figure 5.26 that with increase in fiber length VMA value increases. Sample prepared with fiber and coal ash has shown satisfactory result with respect to design specification for DBM mixture.



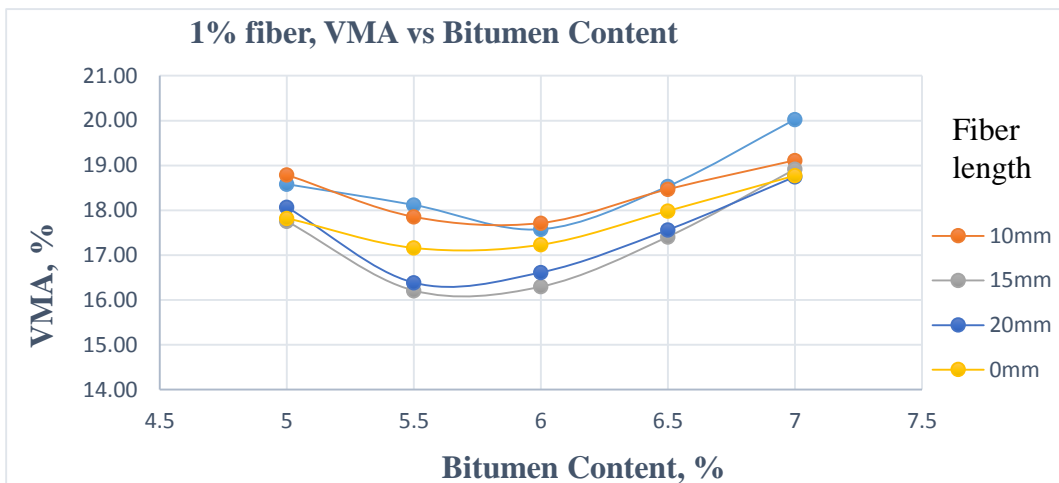
**Figure 5.23 Variation of VMA value with bitumen content in 0.25% fiber content at different fiber length**



**Figure 5.24 Variation of VMA value with bitumen content in 0.5% fiber content at different fiber length**



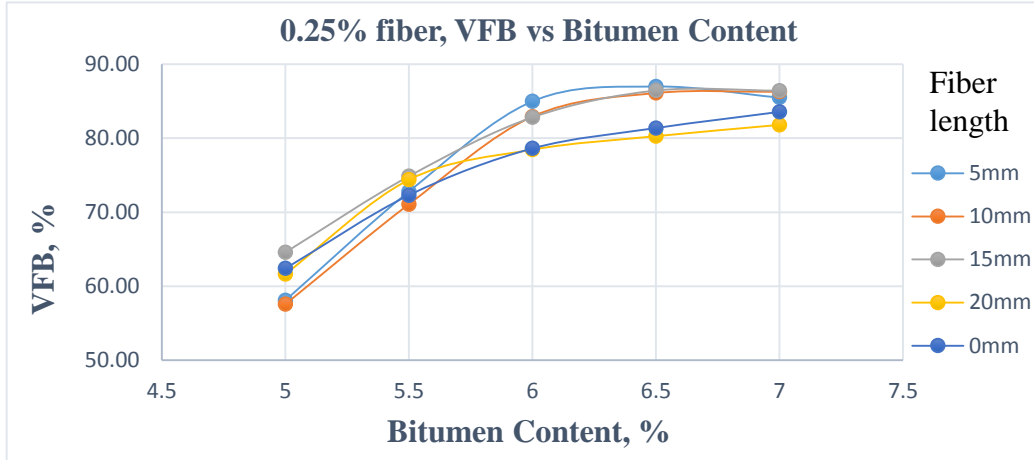
**Figure 5.25 Variation of VMA value with bitumen content in 0.75% fiber content at different fiber length**



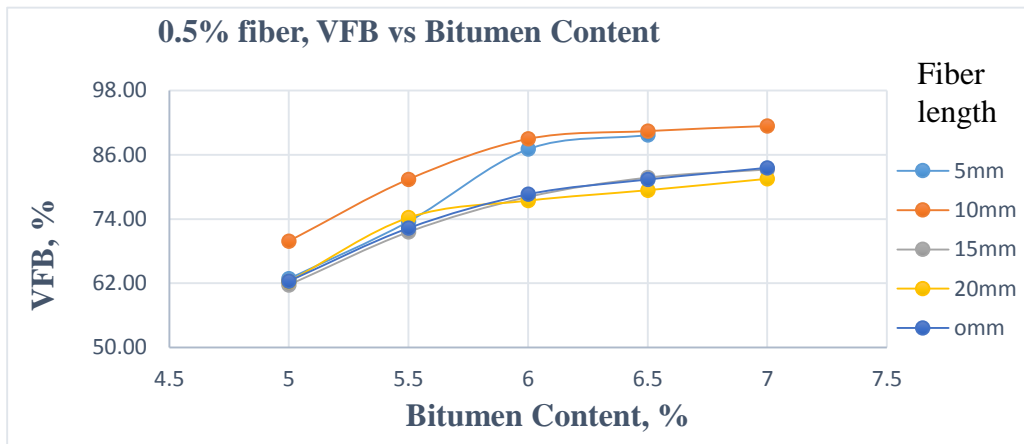
**Figure 5.26 Variation of VMA value with bitumen content in 1% fiber content at different fiber length**

#### 5.4.6 Voids filled with bitumen (VFB)

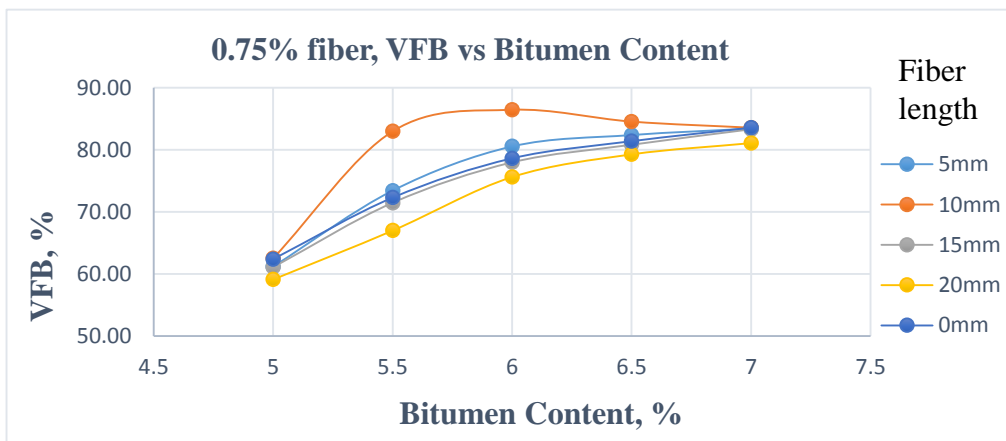
From the figure 5.27 to figure 5.30 it was observe that with increase in binder content VFB increase. It was also observe that for all fiber content and fiber length the VFB value with respect to binder contents are shown better result when compared to the conventional mix.



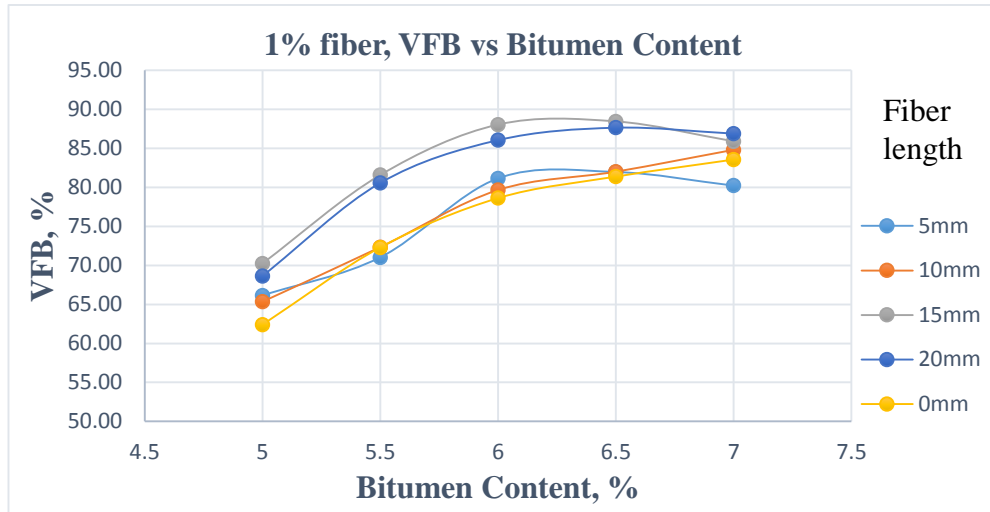
**Figure 5.27 Variation of VFB value with bitumen content in 0.25% fiber content at different fiber length**



**Figure 5.28 Variation of VFB value with bitumen content in 0.5% fiber content at different fiber length**



**Figure 5.29 Variation of VFB value with bitumen content in 0.75% fiber content at different fiber length**



**Figure 5.30 Variation of VFB value with bitumen content in 1% fiber content at different fiber length**

**Table 5.1 Marshall properties analysis**

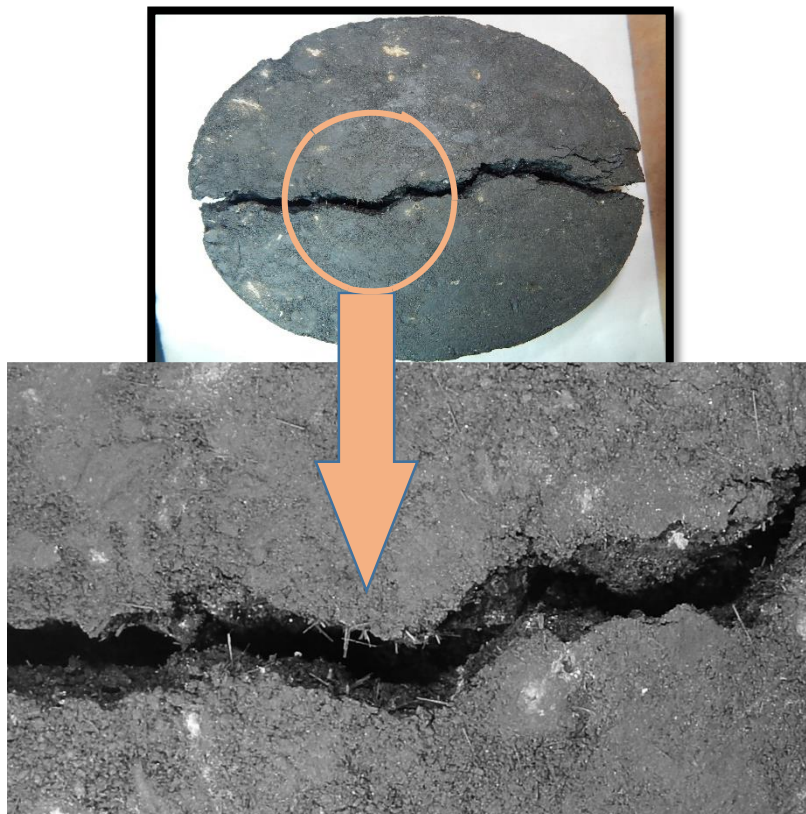
<b>Fiber content, %</b>	<b>Fiber length, mm</b>	<b>OBC, %</b>	<b>Optimum stability, kN</b>	<b>Flow value, mm</b>	<b>VA, %</b>	<b>VMA, %</b>	<b>VFB, %</b>	<b>Gmb</b>
0.25	0	5.60	11.40	3.15	2.40	15.30	84.00	2.33
	5	5.70	14.20	4.00	3.60	16.70	79.00	2.28
	10	5.78	13.20	3.50	3.60	17.00	76.00	2.28
	15	5.87	12.80	3.80	3.10	16.60	80.00	2.27
	20	5.73	11.90	3.80	4.00	17.00	77.00	2.27
<b>Fiber content, %</b>	<b>Fiber length, mm</b>	<b>OBC, %</b>	<b>Optimum stability, kN</b>	<b>Flow value, mm</b>	<b>VA, %</b>	<b>VMA, %</b>	<b>VFB, %</b>	<b>Gmb</b>
0.5	0	5.60	11.40	3.15	2.40	15.30	84.00	2.33
	5	5.57	13.80	3.85	2.90	17.10	75.00	2.26
	10	5.60	15.00	3.50	2.80	15.80	82.00	2.30
	15	5.80	11.50	3.60	4.30	17.60	76.00	2.25
	20	6.13	12.00	4.90	4.00	17.90	78.00	2.24
<b>Fiber content, %</b>	<b>Fiber length, mm</b>	<b>OBC, %</b>	<b>Optimum stability, kN</b>	<b>Flow value, mm</b>	<b>VA, %</b>	<b>VMA, %</b>	<b>VFB, %</b>	<b>Gmb</b>
0.75	0	5.60	11.40	3.15	2.40	15.30	84.00	2.33
	5	5.90	12.20	3.70	3.60	17.30	80.00	2.26
	10	5.77	13.30	3.10	2.20	15.90	86.00	2.30
	15	6.00	12.50	3.40	4.00	17.90	78.00	2.25
	20	6.13	12.30	3.50	4.30	18.35	77.00	2.24
<b>Fiber content, %</b>	<b>Fiber length, mm</b>	<b>OBC, %</b>	<b>Optimum stability, kN</b>	<b>Flow value, mm</b>	<b>VA, %</b>	<b>VMA, %</b>	<b>VFB, %</b>	<b>Gmb</b>
1	0	5.60	11.40	3.15	2.40	15.30	84.00	2.33
	5	5.93	12.30	4.20	3.70	17.60	80.00	2.24
	10	5.77	12.50	3.40	4.40	17.65	76.00	2.24
	15	5.55	13.40	3.20	2.90	16.10	82.00	2.28
	20	5.63	12.65	3.8	2.40	16.20	83.00	2.28

## 5.2. Static indirect tensile test

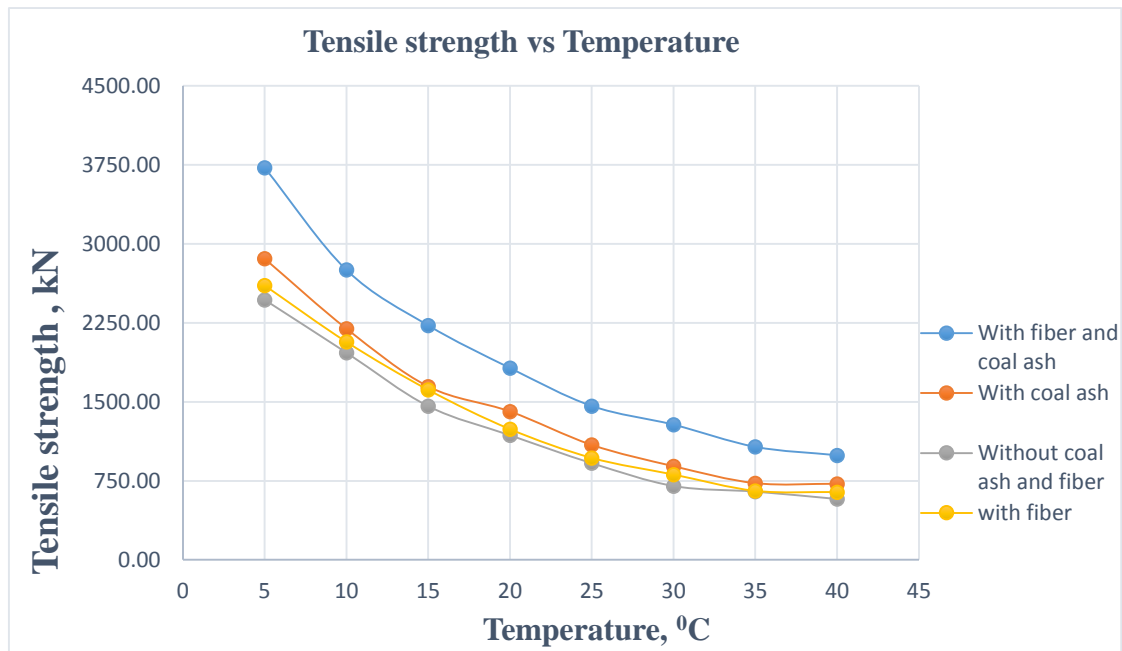
The static indirect tensile test was carried out on four types of samples given below.

- *Sample with fiber and coal ash*
- *Sample with coal ash*
- *Sample without fiber and coal ash*
- *Sample with fiber*

As seen from the graph given in Figure 5.32, as usual with increase in temperature, the indirect tensile strength of any bituminous mix decreases. But with addition of coal ash along with emulsion coated fiber the indirect tensile strength of DBM sample is increased as compared to unmodified conventional mix. This may be possible due to the criss-cross pattern of fibers present in various parts of the mixture resulting in higher strength in tension as shown in figure 5.31. It is also observed that the coal ash also contributes to a marginal increase in tensile strength compared to unmodified conventional mix, which is an advantage.



**Figure 5.31 Criss-cross pattern of sisal fiber at tensile failure crack**



**Figure 5.32 Graph between Tensile strength vs Temperature.**

### 5.3. Resistance to moisture damage (Tensile Strength Ratio (TSR))

The results of tensile strength ratio (TSR) in respect of two different types mixes, one modified and other unmodified are presented in Table 5.2. It was observed that with addition of both fiber and coal ash together, resistance to moisture induced damage was increased as compared to the conventional DBM mixture. This may due to the lesser amount of air voids in modified DBM mixture than unmodified mixture, when prepared with emulsion coated sisal fiber. Similarly from the table 5.1, it is observed that a minimal value of resistance to moisture damage is achieved when the mix was prepared with either fiber or coal ash.

**Table 5.2 TSR of DBM mixes with and without fiber and coal ash.**

Tensile strength ratio			Design requirement
Type of mixes	DBM With coal ash	DBM Without coal ash	Minimum 80% (as per MORTH specification)
DBM With fiber	84.77%	82.04%	
DBM Without fiber	82.35%	80.26%	



## 5.4 Retained stability test

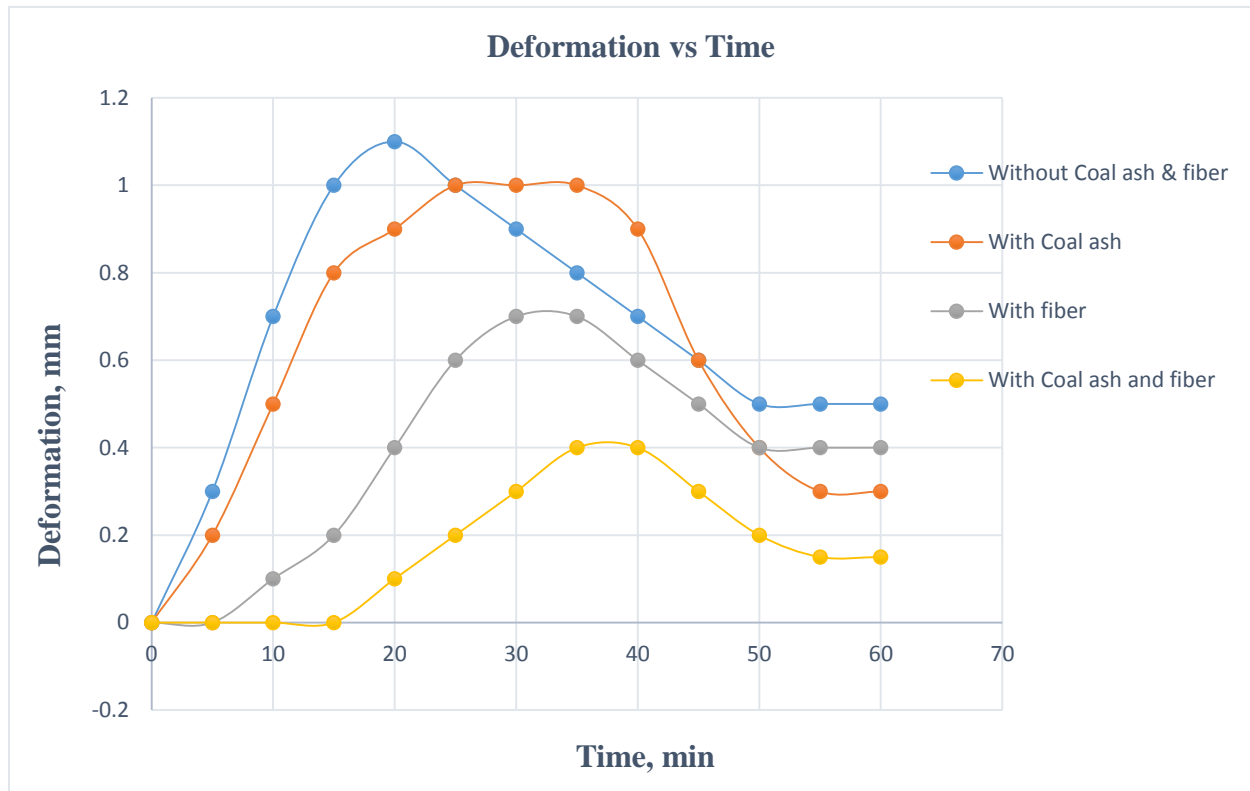
Retained stability was evaluated for DBM sample which were prepared with fiber, coal ash and conventional aggregate and given in table 5.3. It was observed that the sample containing both emulsion coated fiber and coal ash has given higher result than conventional DBM sample. But the sample prepared only with coal ash and conventional aggregate has shown less resistance to moisture and hence given reduced stability than design requirement.

**Table 5.3 Retained stability of DBM mixes with and without fiber and coal ash.**

Retained stability				Design requirement
Type of mixture	Avg. stability after half an hour in water at 60 °c (kN)	Avg. stability after 24 hours in water at 60 °c (kN)	Avg. retained stability (%)	Minimum 75% (as per MORTH specification)
DBM with fiber and Coal ash	14.78	13.21	89.37	
DBM with Coal ash	13.88	10.17	73.21	
DBM with fiber	12.63	10.10	79.94	
DBM without fiber and Coal ash	13.56	10.45	77.03	

## 5.5. Static creep test

Static creep test is a measure of permanent deformation due to constant loading for a long period of time. It was observed from the deformation and time graph shown in figure 5.33 that the deformation value for DBM sample that is prepared with 0.5% fiber content, 10mm fiber length, 14% coal ash (9% bottom ash and 5% fly ash) by weight of the mix and optimum binder content of 5.6% by weight of the mixture decreased when compared with other modified and unmodified DBM mix. It is also seen that with either addition of coal ash or fiber in the mixture, the deformation value decrease when compared to conventional mixture.



**Figure 5.33 Variation of Deformation value at 40<sup>0</sup>C for DBM sample with respect to time**

## **CHAPTER 6**

# **CONCLUDING REMARKS AND FUTURE SCOPE**

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### **6.1 Summary**

Based on experimental study the following conclusions were drawn,

1. From the results of the Marshall tests it was observed that the DBM mixes prepared with bottom ash and fly ash used respectively in 300-75 micron sizes and passing 75 micron resulted best mixes satisfying the Marshall criteria when bitumen content, fiber content and fiber length were 5.6%, 0.5% and 10mm respectively.
2. It is also observed that Marshall stability and flow values are quite acceptable when the coal ash content is within 15%.
3. It is also observed that with increase in fiber content and fiber length, air-void and flow decreases and Marshall Quotient increases which in turn is due to higher stability value.
4. An increase in fiber content and fiber length resulted in higher requirement of optimum bitumen content and emulsion for coating of the fibers.
5. From the indirect tensile strength test it is perceived that the indirect tensile strength of sample increased due to the addition of emulsion coated fiber and coal ash, which gives an excellent engineering property for DBM sample to endure thermal cracking.
6. It is also observed the use of emulsion coated fiber, coal ash or both in DBM mix increases the resistance to moisture induced damages determined in terms of tensile strength ratio and retained stability values.

## 6.2 Future scope

1. As a natural fiber, sisal fiber has shown satisfactory results when used in bituminous mixes. Therefore to utilize the full extent of fibers, other natural fibers such as jute, coconut fiber *etc.* are also taken in to consideration and their effects on DBM bituminous mix should be tested and studied.

2. In this study only SS-1 emulsion was considered as a coating medium for sisal fiber, therefore the effect of other types of emulsion such as rapid setting emulsion (RS) and medium setting (MS) emulsion are taken in to account and subsequent tests should be performed for future study.

3. Furthermore the effect of different mineral fillers such as cement and lime cannot be overlooked. Lime as an anti-stripping agent and cement as a stabilizing agent can be used as potential mineral filler for DBM mix, and subsequent tests may be performed as a part of future scope.

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